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(54) **NITRIDING TREATMENT METHOD FOR STEEL COMPONENT**

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(57) **ABSTRACT**

The invention is a nitriding treatment method for a steel component including at least two nitriding treatment steps, i.e., a first nitriding treatment step in which a nitriding treatment is performed to a steel component under a nitriding gas atmosphere of a first nitriding potential, and a second nitriding treatment step in which another nitriding treatment is performed to the steel component under another nitriding gas atmosphere of a second nitriding potential lower than the first nitriding potential, after the first nitriding treatment step. The first nitriding treatment step and the second nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C. The first nitriding potential is a value within a range of 0.300 to 10.000. The second nitriding potential is a value within a range of 0.253 to 0.600.

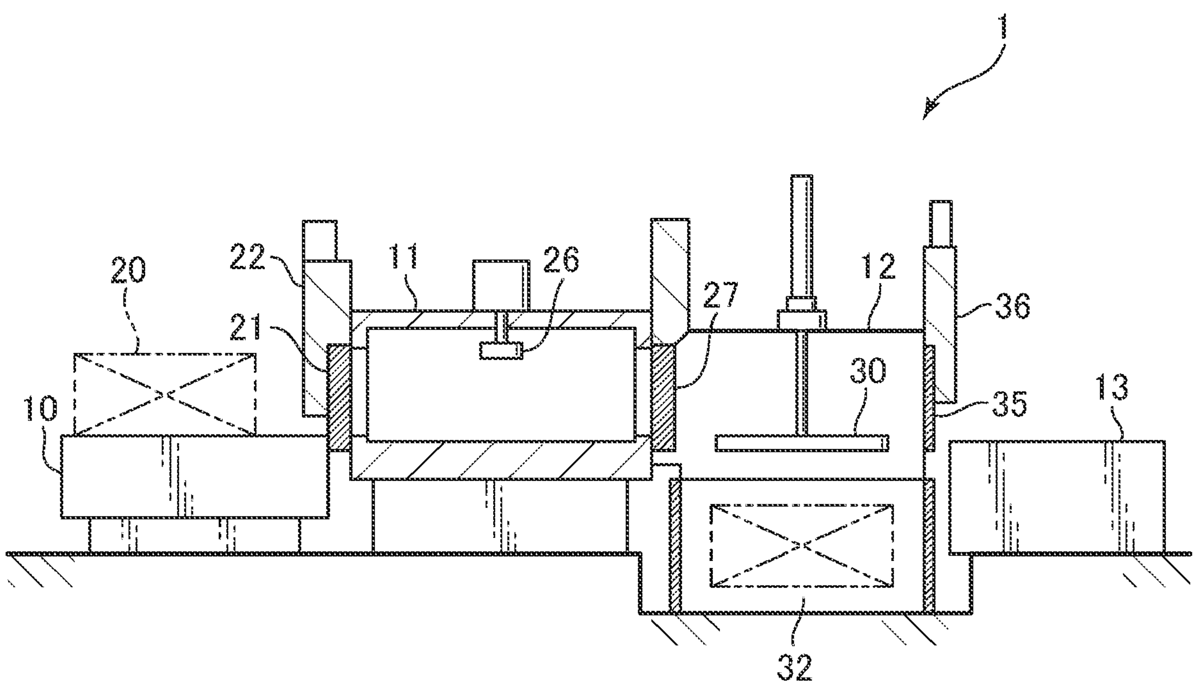


FIG.1

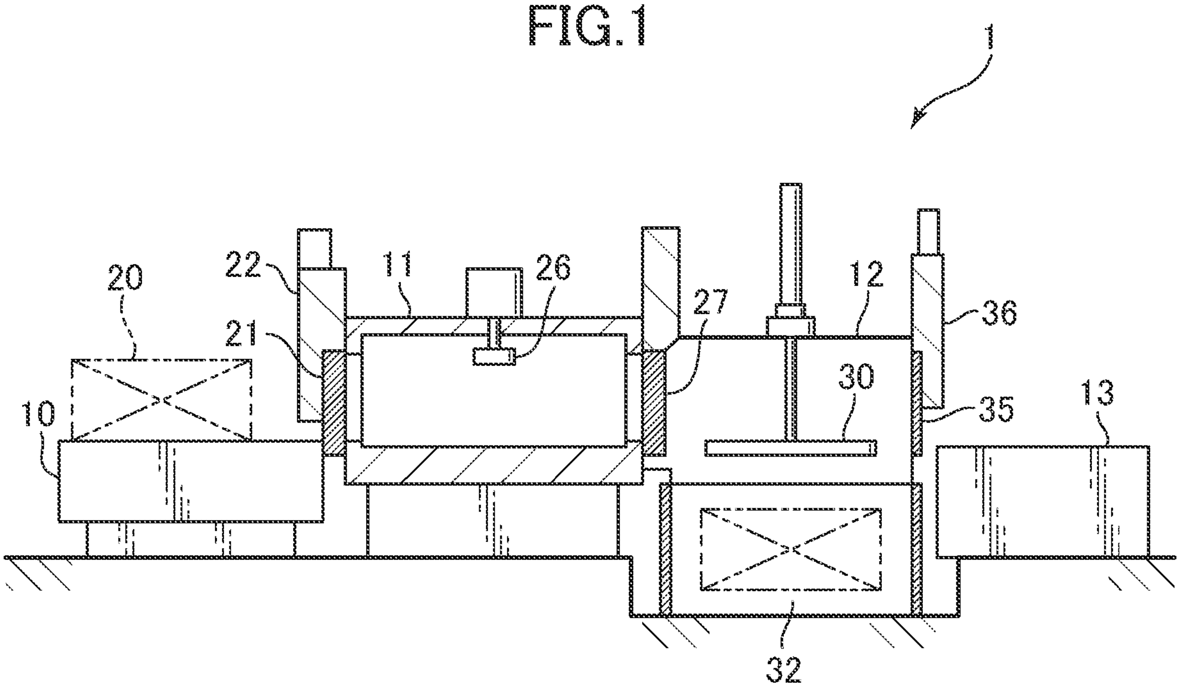


FIG.2

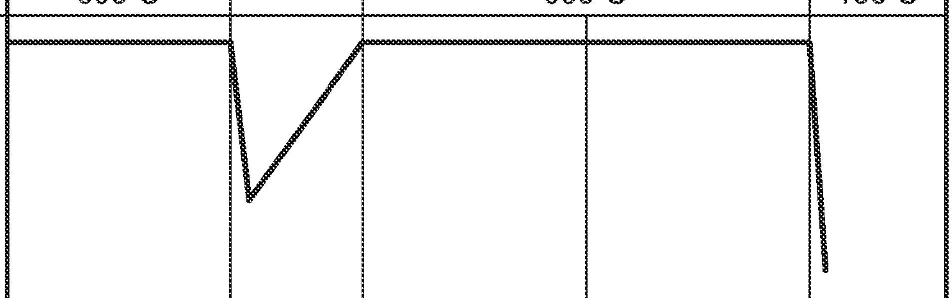
	Before Loading	Loading	Nitriding Treatment		Oil Cooling
Furnace Temperature	550°C		550°C		100°C
					
Time (min)	–	–	240	60	15
N_2(L/min)	70	70	70	–	–
NH_3(L/min)	90	90	Controlled	Controlled	–
AX(L/min)	–	–	Controlled	Controlled	–
Total Gas Flow Amount(L/min)	160	160	160	160	–

FIG.3

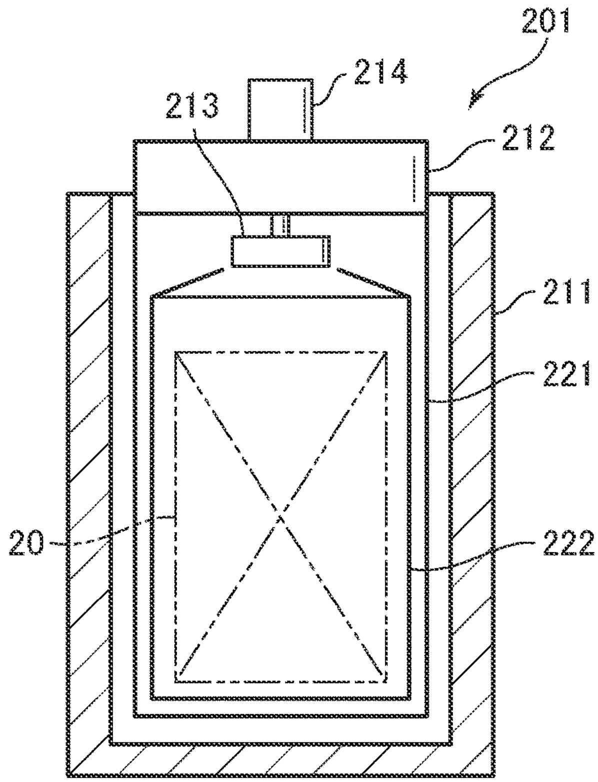


FIG.4

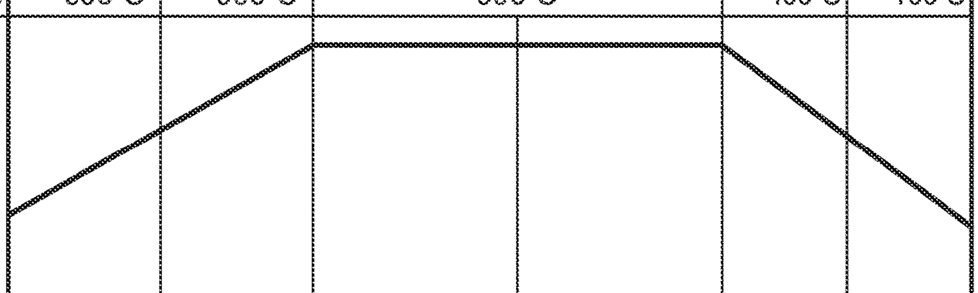
	Temperature Raising		Nitriding Treatment		Temperature Lowering	
Furnace Temperature	~ 350°C	~ 550°C	550°C		~ 400°C	~ 100°C
						
Time (min)	–	–	240	60	–	–
N_2(L/min)	40	–	–	–	–	20
NH_3(L/min)	–	40	Controlled	Controlled	Controlled	–
AX(L/min)	–	–	20	30	30	–

FIG.5

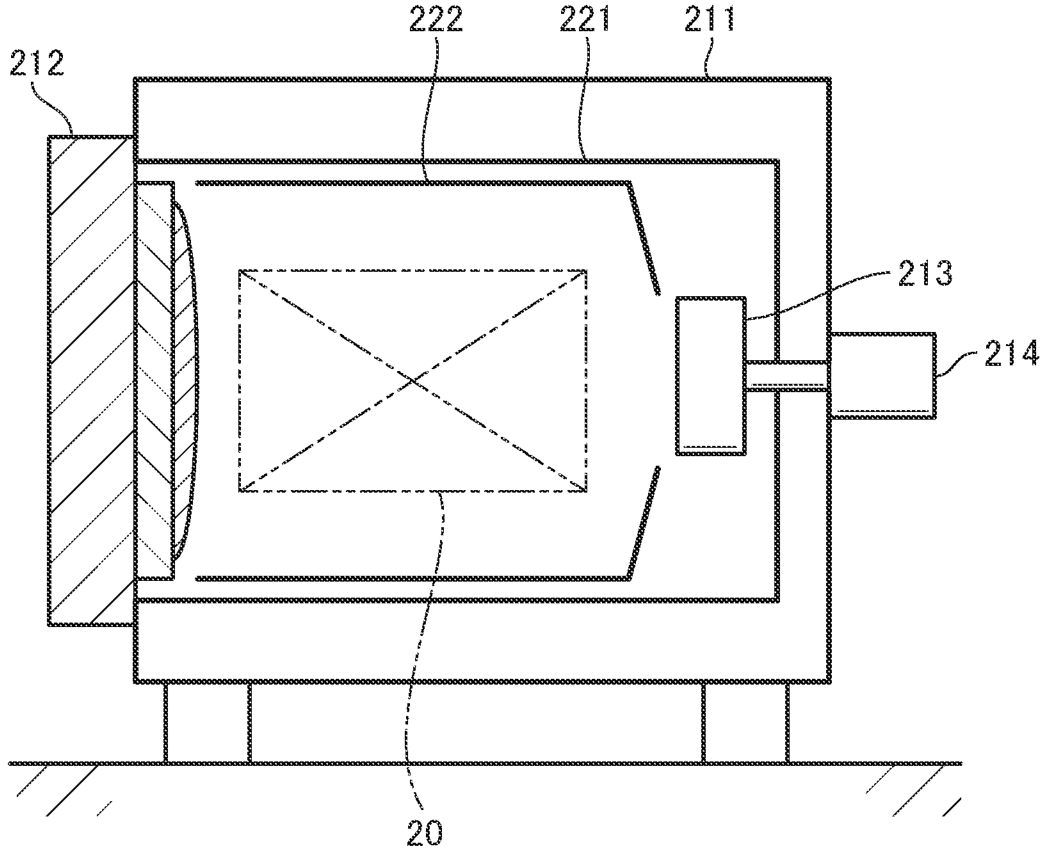


FIG.6

	First Nitriding Treatment Step							Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount							Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	N_2	Total	Temperature	Time	KN	NH_3	AX	Total			
Example1-1	500°C	540min	10	Controlled	Controlled	70(l/min)	160(l/min)	500°C	60min	0.6	Controlled	Controlled	160(l/min)	SCM440	γ'	15 μm
Example1-2	500°C	540min	0.6	Controlled	Controlled	70(l/min)	160(l/min)	500°C	60min	0.5	Controlled	Controlled	160(l/min)	SCM440	γ'	8 μm
Example1-3	520°C	420min	7	Controlled	Controlled	70(l/min)	160(l/min)	520°C	60min	0.45	Controlled	Controlled	160(l/min)	SCr420	γ'	12 μm
Example1-4	550°C	240min	2.5	Controlled	Controlled	70(l/min)	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	SCM415	γ'	12 μm
Example1-5	550°C	240min	2	Controlled	Controlled	70(l/min)	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	S45C	γ'	15 μm
Example1-6	550°C	240min	1.5	Controlled	Controlled	70(l/min)	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	SCM415	γ'	6 μm
Example1-7	570°C	180min	0.7	Controlled	Controlled	70(l/min)	160(l/min)	570°C	60min	0.27	Controlled	Controlled	160(l/min)	SCr420	γ'	6 μm
Example1-8	580°C	120min	1.2	Controlled	Controlled	70(l/min)	160(l/min)	580°C	60min	0.26	Controlled	Controlled	160(l/min)	SCM415	γ'	13 μm
Example1-9	590°C	120min	1	Controlled	Controlled	70(l/min)	160(l/min)	580°C	60min	0.253	Controlled	Controlled	160(l/min)	S45C	γ'	13 μm
Comparative Example1-1	500°C	540min	9	Controlled	Controlled	70(l/min)	160(l/min)	500°C	60min	0.25	Controlled	Controlled	160(l/min)	SCM435	$\gamma'+\alpha$	11 μm
Comparative Example1-2	550°C	240min	2.5	Controlled	Controlled	70(l/min)	160(l/min)	550°C	60min	0.25	Controlled	Controlled	160(l/min)	SCM415	$\gamma'+\alpha$	12 μm
Comparative Example1-3	580°C	120min	1.5	Controlled	Controlled	70(l/min)	160(l/min)	580°C	60min	0.2	Controlled	Controlled	160(l/min)	SCM415	$\gamma'+\alpha$	13 μm
Comparative Example1-4	590°C	120min	1	Controlled	Controlled	70(l/min)	160(l/min)	580°C	60min	0.2	Controlled	Controlled	160(l/min)	S45C	$\gamma'+\alpha$	13 μm

FIG.7

	First Nitriding Treatment Step							Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount							Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	N_2	Total	Temperature	Time	KN	NH_3	AX	Total			
Example2-1	500°C	500min	10	Controlled	Controlled	50(l/min)	120(l/min)	500°C	60min	0.6	Controlled	Controlled	100(l/min)	SCM440	γ'	15 μm
Example2-2	500°C	500min	0.6	Controlled	Controlled	50(l/min)	120(l/min)	500°C	60min	0.5	Controlled	Controlled	100(l/min)	SCM440	γ'	8 μm
Example2-3	520°C	390min	7	Controlled	Controlled	50(l/min)	120(l/min)	520°C	60min	0.45	Controlled	Controlled	100(l/min)	SCr420	γ'	12 μm
Example2-4	550°C	210min	2.5	Controlled	Controlled	50(l/min)	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	SCM415	γ'	12 μm
Example2-5	550°C	210min	2	Controlled	Controlled	50(l/min)	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	S45C	γ'	15 μm
Example2-6	550°C	210min	1.5	Controlled	Controlled	50(l/min)	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	SCM415	γ'	6 μm
Example2-7	570°C	160min	0.7	Controlled	Controlled	50(l/min)	120(l/min)	570°C	60min	0.27	Controlled	Controlled	100(l/min)	SCr420	γ'	6 μm
Example2-8	580°C	110min	1.2	Controlled	Controlled	50(l/min)	120(l/min)	580°C	60min	0.26	Controlled	Controlled	100(l/min)	SCM415	γ'	13 μm
Example2-9	590°C	110min	1	Controlled	Controlled	50(l/min)	120(l/min)	580°C	60min	0.253	Controlled	Controlled	100(l/min)	S45C	γ'	13 μm
Comparative Example2-1	500°C	500min	9	Controlled	Controlled	50(l/min)	120(l/min)	500°C	60min	0.25	Controlled	Controlled	100(l/min)	SCM435	γ'+α	11 μm
Comparative Example2-2	550°C	210min	2.5	Controlled	Controlled	50(l/min)	120(l/min)	550°C	60min	0.25	Controlled	Controlled	100(l/min)	SCM415	γ'+α	12 μm
Comparative Example2-3	580°C	110min	1.5	Controlled	Controlled	50(l/min)	120(l/min)	580°C	60min	0.2	Controlled	Controlled	100(l/min)	SCM415	γ'+α	13 μm
Comparative Example2-4	590°C	110min	1	Controlled	Controlled	50(l/min)	120(l/min)	580°C	60min	0.2	Controlled	Controlled	100(l/min)	S45C	γ'+α	13 μm

FIG.8

	First Nitriding Treatment Step						Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount						Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	Total	Temperature	Time	KN	NH_3	AX	Total			
Example3-1	500°C	540min	10	Controlled	Controlled	160(l/min)	500°C	60min	0.6	Controlled	Controlled	160(l/min)	SCM440	γ'	13 μm
Example3-2	500°C	540min	0.6	Controlled	Controlled	160(l/min)	500°C	60min	0.5	Controlled	Controlled	160(l/min)	SCM440	γ'	7 μm
Example3-3	520°C	420min	7	Controlled	Controlled	160(l/min)	520°C	60min	0.45	Controlled	Controlled	160(l/min)	SCr420	γ'	11 μm
Example3-4	550°C	240min	2.5	Controlled	Controlled	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	SCM415	γ'	11 μm
Example3-5	550°C	240min	2	Controlled	Controlled	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	S45C	γ'	14 μm
Example3-6	550°C	240min	1.5	Controlled	Controlled	160(l/min)	550°C	60min	0.3	Controlled	Controlled	160(l/min)	SCM415	γ'	5 μm
Example3-7	570°C	180min	0.7	Controlled	Controlled	160(l/min)	570°C	60min	0.27	Controlled	Controlled	160(l/min)	SCr420	γ'	5 μm
Example3-8	580°C	120min	1.2	Controlled	Controlled	160(l/min)	580°C	60min	0.26	Controlled	Controlled	160(l/min)	SCM415	γ'	12 μm
Example3-9	590°C	120min	1	Controlled	Controlled	160(l/min)	580°C	60min	0.253	Controlled	Controlled	160(l/min)	S45C	γ'	12 μm
Comparative Example3-1	500°C	540min	9	Controlled	Controlled	160(l/min)	500°C	60min	0.25	Controlled	Controlled	160(l/min)	SCM435	γ'+α	10 μm
Comparative Example3-2	550°C	240min	2.5	Controlled	Controlled	160(l/min)	550°C	60min	0.25	Controlled	Controlled	160(l/min)	SCM415	γ'+α	11 μm
Comparative Example3-3	580°C	120min	1.5	Controlled	Controlled	160(l/min)	580°C	60min	0.2	Controlled	Controlled	160(l/min)	SCM415	γ'+α	12 μm
Comparative Example3-4	590°C	120min	1	Controlled	Controlled	160(l/min)	580°C	60min	0.2	Controlled	Controlled	160(l/min)	S45C	γ'+α	12 μm

FIG.9

	First Nitriding Treatment Step						Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount						Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	Total	Temperature	Time	KN	NH_3	AX	Total			
Example4-1	500°C	500min	10	Controlled	Controlled	120(l/min)	500°C	60min	0.6	Controlled	Controlled	100(l/min)	SCM440	γ'	14 μm
Example4-2	500°C	500min	0.6	Controlled	Controlled	120(l/min)	500°C	60min	0.5	Controlled	Controlled	100(l/min)	SCM440	γ'	7 μm
Example4-3	520°C	390min	7	Controlled	Controlled	120(l/min)	520°C	60min	0.45	Controlled	Controlled	100(l/min)	SCr420	γ'	11 μm
Example4-4	550°C	210min	2.5	Controlled	Controlled	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	SCM415	γ'	11 μm
Example4-5	550°C	210min	2	Controlled	Controlled	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	S45C	γ'	13 μm
Example4-6	550°C	210min	1.5	Controlled	Controlled	120(l/min)	550°C	60min	0.3	Controlled	Controlled	100(l/min)	SCM415	γ'	5 μm
Example4-7	570°C	160min	0.7	Controlled	Controlled	120(l/min)	570°C	60min	0.27	Controlled	Controlled	100(l/min)	SCr420	γ'	5 μm
Example4-8	580°C	110min	1.2	Controlled	Controlled	120(l/min)	580°C	60min	0.26	Controlled	Controlled	100(l/min)	SCM415	γ'	11 μm
Example4-9	590°C	110min	1	Controlled	Controlled	120(l/min)	580°C	60min	0.253	Controlled	Controlled	100(l/min)	S45C	γ'	11 μm
Comparative Example4-1	500°C	500min	9	Controlled	Controlled	120(l/min)	500°C	60min	0.25	Controlled	Controlled	100(l/min)	SCM435	γ'+α	10 μm
Comparative Example4-2	550°C	210min	2.5	Controlled	Controlled	120(l/min)	550°C	60min	0.25	Controlled	Controlled	100(l/min)	SCM415	γ'+α	11 μm
Comparative Example4-3	580°C	110min	1.5	Controlled	Controlled	120(l/min)	580°C	60min	0.2	Controlled	Controlled	100(l/min)	SCM415	γ'+α	12 μm
Comparative Example4-4	590°C	110min	1	Controlled	Controlled	120(l/min)	580°C	60min	0.2	Controlled	Controlled	100(l/min)	S45C	γ'+α	12 μm

FIG.10

	First Nitriding Treatment Step						Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount						Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	Total	Temperature	Time	KN	NH_3	AX	Total			
Example5-1	500°C	500min	10	Controlled	50(l/min)	Variable	500°C	60min	0.6	Controlled	50(l/min)	Variable	SCM440	γ'	15 μm
Example5-2	500°C	500min	0.6	Controlled	50(l/min)	Variable	500°C	60min	0.5	Controlled	50(l/min)	Variable	SCM440	γ'	8 μm
Example5-3	520°C	390min	7	Controlled	50(l/min)	Variable	520°C	60min	0.45	Controlled	50(l/min)	Variable	SCr420	γ'	12 μm
Example5-4	550°C	210min	2.5	50(l/min)	Controlled	Variable	550°C	60min	0.3	50(l/min)	Controlled	Variable	SCM415	γ'	12 μm
Example5-5	550°C	210min	2	Controlled	50(l/min)	Variable	550°C	60min	0.3	Controlled	50(l/min)	Variable	S45C	γ'	15 μm
Example5-6	550°C	210min	1.5	Controlled	50(l/min)	Variable	550°C	60min	0.3	Controlled	50(l/min)	Variable	SCM415	γ'	6 μm
Example5-7	570°C	160min	0.7	50(l/min)	Controlled	Variable	570°C	60min	0.27	50(l/min)	Controlled	Variable	SCr420	γ'	6 μm
Example5-8	580°C	110min	1.2	Controlled	50(l/min)	Variable	580°C	60min	0.26	Controlled	50(l/min)	Variable	SCM415	γ'	13 μm
Example5-9	590°C	110min	1	Controlled	50(l/min)	Variable	580°C	60min	0.253	Controlled	50(l/min)	Variable	S45C	γ'	13 μm
Comparative Example5-1	500°C	500min	9	Controlled	50(l/min)	Variable	500°C	60min	0.25	Controlled	50(l/min)	Variable	SCM435	$\gamma'+\alpha$	11 μm
Comparative Example5-2	550°C	210min	2.5	Controlled	50(l/min)	Variable	550°C	60min	0.25	Controlled	50(l/min)	Variable	SCM415	$\gamma'+\alpha$	12 μm
Comparative Example5-3	580°C	110min	1.5	50(l/min)	Controlled	Variable	580°C	60min	0.2	50(l/min)	Controlled	Variable	SCM415	$\gamma'+\alpha$	13 μm
Comparative Example5-4	590°C	110min	1	Controlled	50(l/min)	Variable	580°C	60min	0.2	Controlled	50(l/min)	Variable	S45C	$\gamma'+\alpha$	13 μm

FIG.11

	First Nitriding Treatment Step							Second Nitriding Treatment Step						Used Steel Type	Identification Result of Phase (XRD)	Thickness of Compound Layer
				Gas Flow Amount							Gas Flow Amount					
	Temperature	Time	KN	NH_3	AX	N_2	Total	Temperature	Time	KN	NH_3	AX	Total			
Example6-1	500°C	540min	10	Controlled	50(l/min)	Controlled	Variable	500°C	60min	0.6	Controlled	50(l/min)	Variable	SCM440	γ'	15 μm
Example6-2	500°C	540min	0.6	Controlled	50(l/min)	Controlled	Variable	500°C	60min	0.5	Controlled	50(l/min)	Variable	SCM440	γ'	8 μm
Example6-3	520°C	420min	7	Controlled	50(l/min)	Controlled	Variable	520°C	60min	0.45	Controlled	50(l/min)	Variable	SCr420	γ'	12 μm
Example6-4	550°C	240min	2.5	50(l/min)	Controlled	Controlled	Variable	550°C	60min	0.3	50(l/min)	Controlled	Variable	SCM415	γ'	12 μm
Example6-5	550°C	240min	2	Controlled	50(l/min)	Controlled	Variable	550°C	60min	0.3	Controlled	50(l/min)	Variable	S45C	γ'	15 μm
Example6-6	550°C	240min	1.5	Controlled	50(l/min)	Controlled	Variable	550°C	60min	0.3	Controlled	50(l/min)	Variable	SCM415	γ'	6 μm
Example6-7	570°C	180min	0.7	50(l/min)	Controlled	Controlled	Variable	570°C	60min	0.27	50(l/min)	Controlled	Variable	SCr420	γ'	6 μm
Example6-8	580°C	120min	1.2	Controlled	50(l/min)	Controlled	Variable	580°C	60min	0.26	Controlled	50(l/min)	Variable	SCM415	γ'	13 μm
Example6-9	590°C	120min	1	Controlled	50(l/min)	Controlled	Variable	580°C	60min	0.253	Controlled	50(l/min)	Variable	S45C	γ'	13 μm
Comparative Example6-1	500°C	540min	9	Controlled	50(l/min)	Controlled	Variable	500°C	60min	0.25	Controlled	50(l/min)	Variable	SCM435	$\gamma'+\alpha$	11 μm
Comparative Example6-2	550°C	240min	2.5	Controlled	50(l/min)	Controlled	Variable	550°C	60min	0.25	Controlled	50(l/min)	Variable	SCM415	$\gamma'+\alpha$	12 μm
Comparative Example6-3	580°C	120min	1.5	50(l/min)	Controlled	Controlled	Variable	580°C	60min	0.2	50(l/min)	Controlled	Variable	SCM415	$\gamma'+\alpha$	13 μm
Comparative Example6-4	590°C	120min	1	Controlled	50(l/min)	Controlled	Variable	580°C	60min	0.2	Controlled	50(l/min)	Variable	S45C	$\gamma'+\alpha$	13 μm

NITRIDING TREATMENT METHOD FOR STEEL COMPONENT

TECHNICAL FIELD

[0001] The present invention relates to a nitriding treatment method for a steel component which comprises at least two nitriding treatment steps.

BACKGROUND ART

[0002] For a steel component such as a gear used in a transmission for an automobile, a high pitting resistance and a high bending fatigue strength are required. In order to meet such requirements, a carburizing treatment and/or a nitriding treatment are known as a technique for reinforcing such a steel component such as a gear.

[0003] For example, JP-A-2013-221203 (JP application number 2012-095035) (Patent Document 1) has disclosed that, in order to improve a pitting resistance and/or flexural fatigue strength of a steel component, it is effective to produce an iron nitride compound layer having a γ' phase as a main component on a surface of the steel component by a nitriding treatment.

[0004] In addition, JP-B-6378189 (Patent Document 2) has disclosed a nitriding treatment method including a first nitriding treatment step in which a nitriding treatment is performed to a steel component under a nitriding gas atmosphere of a nitriding potential for generating a nitride compound layer of a γ' phase or an c phase, and a second nitriding treatment step in which another nitriding treatment is performed to the steel component under another nitriding gas atmosphere of another nitriding potential lower than that of the first nitriding treatment step resulting in deposition of a γ' phase in the nitride compound layer, in order to suppress variation in mass production. Specifically, a gas nitriding treatment performed at a temperature of 600° C. using two types of gases, which are an NH_3 gas and an H_2 gas, is described as an example. More specifically, at a temperature of 600° C., a range of 0.6 to 1.51 is adopted for the nitriding potential in the first nitriding treatment step, and a range of 0.16 to 0.25 is adopted for the nitriding potential in the second nitriding treatment step.

Prior Document

[0005] The Patent Document 1 cited in the present specification is JP-A-2013-221203 (JP application number 2012-095035).

[0006] The Patent Document 2 cited in the present specification is JP-B-6378189. Summary of Invention

Technical Problem

[0007] The present inventor has further studied the nitriding treatment method disclosed in JP-B-6378189 (Patent Document 2), and has found that, in a temperature range of 500° C. to 590° C., setting the nitriding potential at the second nitriding treatment step to be higher than 0.25 is more effective in depositing the γ' phase in the nitride compound layer.

[0008] According to the present inventor, the action (reaction) in which the γ' phase is deposited in the nitride compound layer is affected by both the nitriding potential and the furnace temperature. In a temperature range of 500° C. to 590° C., if the nitriding potential at the second nitriding treatment step is set to be 0.25 or less, an a phase which is lower in hardness than the γ' phase is also deposited. This results in an insufficient pitting resistance and/or an insufficient bending fatigue strength.

[0009] The present invention has been made based on the above findings. It is an object of the present invention to provide a nitriding treatment method to be performed in a temperature range of 500° C. to 590° C., which enables a γ' phase to be deposited in a nitride compound layer in a suitable manner and thus achieves a high pitting resistance and a high bending fatigue strength.

Solution to Problem

[0010] The present invention is a nitriding treatment method for a steel component, including at least two nitriding treatment steps, i.e., a first nitriding treatment step in which a nitriding treatment is performed to a steel component under a nitriding gas atmosphere of a first nitriding potential, and a second nitriding treatment step in which another nitriding treatment is performed to the steel component under another nitriding gas atmosphere of a second nitriding potential lower than the first nitriding potential, after the first nitriding treatment step, wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., the first nitriding potential is a value within a range of 0.300 to 10.000, the second nitriding potential is a value within a range of 0.253 to 0.600, a nitride compound layer consisting of a γ' phase, or an ε phase, or mixture of a γ' phase and an ε phase, is generated during the first nitriding treatment step, and a γ' phase is deposited in the nitride compound layer during the second nitriding treatment step.

[0011] According to the present invention, since the second nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C. and the second nitriding potential is a value within a range of 0.253 to 0.600, the γ' phase can be deposited in the nitride compound layer in a suitable manner while an a phase, which is lower in hardness than the γ' phase, is inhibited to be deposited therein. Thus, a high pitting resistance and a high bending fatigue strength can be achieved.

[0012] In the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a batch type of thermal processing furnace; three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0013] In the above control manner, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been proved.

[0014] Alternatively, in the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace: three type of gases, which are an NH_3 gas, an AX gas and an N_2 gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0015] In the above control manner as well, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been proved.

[0016] Alternatively, in the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a batch type of thermal processing furnace; two types of gases, which are an NH_3 gas and an AX gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0017] In the above control manner as well, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been proved.

[0018] Alternatively, in the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace; two types of gases, which are an NH_3 gas and an AX gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant

[0019] In the above control manner as well, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been

[0020] Alternatively, in the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace; two types of gases, which are an NH_3 gas and an AX gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

[0021] In the above control manner as well, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been

[0022] Alternatively, in the present invention, for example, the first nitriding treatment step and the second nitriding treatment step may be performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace; three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, may be used in the first nitriding treatment step; a nitriding potential during the first nitriding treatment step may be controlled to be close to the first nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant; two types of gases, which are an NH_3 gas and an AX gas, may be used in the second nitriding treatment step; and a nitriding potential during the second nitriding treatment step may be controlled to be close to the second nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

[0023] In the above control manner as well, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, has been

[0024] Herein, the one-chamber type of thermal processing furnace means a thermal processing furnace which does not include a chamber for a cooling step separately from a chamber for a heating step like in the batch type of thermal processing furnace (see FIG. **1**) and in which both the heating step and the cooling step are conducted to only one chamber. A pit type furnace (see FIG. **3**) and a horizontal type furnace (see FIG. **5**) are common examples.

[0025] In addition, in the above respective inventions, it is preferable that a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed. According to the inventors finding, by performing the first nitriding treatment step longer than the second nitriding treatment step, it is possible to adjust a thickness of the compound layer after the nitriding treatment to a desired thickness.

Advantageous Effects of Invention

[0026] According to the present invention, since the second nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C. and the second nitriding potential is a value within a range of 0.253 to 0.600, the γ' phase can be deposited in the nitride compound layer in a suitable manner while an a phase, which is lower in hardness than the γ' phase, is inhibited to be deposited therein.

[0027] Thus, a high pitting resistance and a high bending fatigue strength can be achieved.

BRIEF DESCRIPTION OF DRAWINGS

[0028] FIG. **1** is a schematic view showing a structure of a batch type of thermal processing furnace to be used for a nitriding treatment method according to the present invention:

[0029] FIG. **2** is a process diagram of an embodiment of the nitriding treatment method according to the present invention in a case wherein the thermal processing furnace shown in FIG. **1** is used;

[0030] FIG. **3** is a schematic view showing a structure of a pit type thermal processing furnace (one-chamber type of thermal processing furnace) to be used for a nitriding treatment method according to the present invention;

[0031] FIG. **4** is a process diagram of an embodiment of the nitriding treatment method according to the present invention in a case wherein the thermal processing furnace shown in FIG. **3** is used;

[0032] FIG. **5** is a schematic view showing a structure of a horizontal type thermal processing furnace (one-chamber type of thermal processing furnace) to be used for a nitriding treatment method according to the present invention:

[0033] FIG. **6** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention;

[0034] FIG. **7** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention;

[0035] FIG. **8** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention;

[0036] FIG. **9** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention;

[0037] FIG. **10** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention; and

[0038] FIG. **11** is a table showing nitriding conditions and treatment results of examples and comparative examples of the present invention.

DESCRIPTION OF EMBODIMENTS

(Example of Object to be Processed (Work))

[0039] An object to be processed (a work) is a steel component. Specifically, it is a steel component consisting of a carbon steel component used for a machine structure or an alloy steel component used for a machine structure, such as a gear used for an automatic transmission. For example, a plurality of cylindrical ring gears or a plurality of bottomed cylindrical ring gears are mounted on a plurality of stages of jigs, placed in a flat state in a case (described below), and subjected to a nitriding treatment.

[0040] Preferably, the steel component is pre-cleaned to remove dirt and oil before being subjected to the nitriding treatment. The pre-cleaning process is preferably, for example, a vacuum cleaning process for degreasing and drying by dissolving and replacing oil or the like with a hydrocarbon-based cleaning liquid and evaporating it, an alkali cleaning process for degreasing with an alkaline-based cleaning liquid, or the like.

(Structural Example of Batch Type of Thermal Processing Furnace)

[0041] FIG. **1** is a schematic view showing a structure of a batch type of thermal processing furnace **1** to be used for a nitriding treatment method according to the present invention.

[0042] As shown in FIG. **1**, the batch type of thermal processing furnace **1** includes a loading section **10**, a heating chamber **11**, a transfer chamber **12**, and an unloading conveyor **13**. A case **20** is configured to be loaded into the loading section **10**. A steel component as an object to be processed (work) is configured to be contained in the case **20**. The maximum gross weight to be processed is 700 kg.

[0043] An inlet hood **22** having an openable and closable door **21** is attached to an inlet side (left side in FIG. **1**) of the heating chamber **11**. The heating chamber **11** has a retort structure, and an outer periphery of the retort structure is configured to be heated by a heater (not shown) so that a temperature in the furnace (chamber) is controlled to a predetermined temperature. A plurality of types of gases for the nitriding treatment are configured to be introduced into the heating chamber **11** while being controlled as described below.

[0044] A fan **26** is mounted on a ceiling of the heating chamber **11** to stir the gases introduced into the heating chamber **11** so that a heating temperature for the steel component is made uniform therein. An openable and closable intermediate door **27** is attached to an exit side (right side in FIG. **1**) of the heating chamber **11**.

[0045] The transfer chamber **12** is provided with an elevator **30** for raising and lowering the case **20** that contains the steel component. A lower part of the transfer chamber **12** is provided with a cooling chamber (oil tank) **32** in which a cooling oil **31** is stored. An outlet hood **36** having an openable and closable door is attached to an outlet side (right side in FIG. **1**) of the transfer chamber **12**

[0046] The heating chamber **11** and the transfer chamber **12** may be the same processing space, and a configuration for air-cooling the thermally-processed steel component with a gas may be employed. Alternatively, the heating chamber **11** may be divided into two chambers, and a two-stage nitriding treatment as described below may be performed in the respective two chambers.

(Operational Example of Batch Type of Thermal Processing Furnace)

[0047] In the thermal processing furnace **1** as described above, the case **20** that contains the steel component is loaded into the heating chamber **11** from the loading section **10** by a pusher or the like. After the steel component (the case that contains the steel component) is loaded into the heating chamber **11**, the plurality of types of process gases are introduced into the heating chamber **11**, and the process gases are heated to a predetermined temperature by the heater and stirred by the fan **26** (for example, rotating at 1500 rpm) so that the steel component loaded into the heating chamber **11** is subjected to the nitriding treatment.

[0048] FIG. **2** is a process diagram of an embodiment of the nitriding treatment method according to the present invention in a case wherein the thermal processing furnace **1** shown in FIG. **1** is used.

[0049] In the example shown in FIG. **2**, before a steel component (work) is loaded into the heating chamber **11**, the heating chamber **11** is pre-heated to 550° C. in advance. During this pre-heating step, an N_2 gas is introduced at a constant flow rate of 70 (L/min), and an NH_3 gas is introduced at a constant flow rate of 90 (L/min). That is to say, the total amount (flow rate) thereof is 70+90=160 (L/min).

[0050] Then, a steel component (work) is loaded into the heating chamber **11**. At this time, the door **21** is opened, and thus the temperature in the heating chamber **11** is temporarily lowered as shown in FIG. **2**. Thereafter, the door **21** is closed and the temperature in the heating chamber **11** is heated again to 550° C.

[0051] During this loading step as well, in the example shown in FIG. **2**, the N_2 gas continues to be introduced at the constant flow rate of 70 (L/min), and the NH_3 gas continues to be introduced at the constant flow rate of 90 (L/min). That is to say, the total amount (flow rate) thereof continues to be 70+90=160 (L/min).

[0052] Thereafter, a two-stage nitriding treatment is performed. Specifically, at first, for example, a value of 1.500 (an example of a value within a range of 0.300 to 10.000) is employed as a first nitriding potential, and a first nitriding treatment step is performed at a temperature of 550° C.

[0053] It is known that a nitriding potential K_N is represented by the following formula using $P(NH_3)$ which is a partial pressure of the NH_3 gas and $P(H_2)$ which is a partial pressure of the H_2 gas.

$$K_N = P(NH_3)/P(H_2)^{3/2}$$

[0054] In the first nitriding treatment step, $P(NH_3)$ i.e. a partial pressure of the NH_3 gas in the heating chamber **11** or $P(H_2)$ i.e. a partial pressure of the H_2 gas in the heating chamber **11** is measured. Then, the introduction amounts (flow rates) of the process gases are subjected to a feedback control in such a manner that a nitriding potential calculated from the measured value is brought into the vicinity of the first nitriding potential, which is a target nitriding potential.

[0055] In the example shown in FIG. **2**, $P(H_2)$ i.e. a partial pressure of the H_2 gas in the heating chamber **11** is measured by a heat conduction type H_2 sensor (not shown), the measured value is analyzed online (so that a nitriding potential is calculated from the measured value), and the introduction amounts (flow rates) of the process gases are subjected to a feedback control. Specifically, the N_2 gas continues to be introduced at the constant flow rate of 70 (L/min), but the introduction amounts (flow rates) of the NH_3 gas and an AX gas are respectively increased or decreased while keeping the sum amount of the two gases to be 90 (L/min). That is to say, the total amount of the three gases continues to be 70+90=160 (L/min).

[0056] In the example shown in FIG. **2**, the first nitriding treatment step is performed for 240 minutes. Thereby, a nitride compound layer consisting of a γ' phase, or an ε phase, or mixture of a γ' phase and an ε phase, is generated in the steel component.

[0057] Subsequently, for example, a value of 0.300 (an example of a value within a range of 0.253 to 0.600) is employed as a second nitriding potential, and a second nitriding treatment step is performed at a temperature of 550° C.

[0058] In the second nitriding treatment step as well, $P(NH_3)$ i.e. a partial pressure of the NH_3 gas in the heating chamber **11** or $P(H_2)$ i.e. a partial pressure of the H_2 gas in the heating chamber **11** is measured. Then, the introduction amounts (flow rates) of the process gases are subjected to a feedback control in such a manner that a nitriding potential calculated from the measured value is brought into the vicinity of the second nitriding potential, which is a target nitriding potential.

[0059] In the example shown in FIG. **2**, $P(H_2)$ i.e. a partial pressure of the H_2 gas in the heating chamber **11** is measured by the heat conduction type H_2 sensor (not shown), the measured value is analyzed online (so that a nitriding potential is calculated from the measured value), and the introduction amounts (flow rates) of the process gases are subjected to a feedback control. Specifically, the introduction amounts (flow rates) of the NH_3 gas and the AX gas are respectively increased or decreased while keeping the sum (total) amount of the two gases to be 160 (L/min).

[0060] In the example shown in FIG. **2**, the second nitriding treatment step is performed for 60 minutes. Thereby, a γ' phase is deposited in the nitride compound layer.

[0061] After the second nitriding treatment step has been completed, a cooling step is performed. In the example shown in FIG. **2**, the cooling step is performed for 15 minutes (the case **20** is held in the oil bath (100° C.) for 15 minutes, the oil bath being provided with a stirrer). After the cooling step has been completed, the case **20** that contains the steel component is unloaded onto the unloading conveyor **13**.

(Structural Example of Pit Type Thermal Processing Furnace)

[0062] FIG. **3** is a schematic view showing a structure of a pit type thermal processing furnace **201** to be used for a nitriding treatment method according to the present invention.

[0063] As shown in FIG. **3**, the pit type thermal processing furnace **201** includes a bottomed cylindrical furnace wall **211** and a furnace lid **212**.

[0064] A fan **213** is provided on a lower (inner) side of the furnace lid **212**. A rotation shaft of the fan **213** passes through the furnace lid **212**, and is connected to a fan motor **214**, which is provided on an upper (outer) side of the furnace lid **212**.

[0065] A retort **221** is provided inside the furnace wall **211**. A gas guide tube **222** is provided further inside the retort **221**. An outer periphery of the retort **221** is configured to be heated by a heater (not shown) so that a temperature in the furnace (in the retort **221**) is controlled to a predetermined temperature. A case is configured to be placed into the gas guide tube **222**. A steel component as an object to be processed (work) is configured to be contained in the case **20**. The maximum gross weight to be processed is 700 kg.

[0066] A plurality of types of gases for the nitriding treatment are configured to be introduced into the retort **221** while being controlled as described below. In addition, the outer periphery of the retort **221** has a cooling function by a blower (not shown). When cooled, a temperature of the retort **221** itself is lowered, and thus the temperature in the furnace (in the retort **221**) is lowered (furnace cooling).

(Operational Example of Pit Type Thermal Processing Furnace)

[0067] In the thermal processing furnace **201** as described above, the furnace lid **212** is opened, and the case **20** that contains the steel component is loaded into the gas guide tube **222**. After the steel component (the case **20** that contains the steel component) has been loaded into the gas guide tube **222**, the plurality of types of process gases are introduced into the gas guide tube **222**, and the process gases are heated to a predetermined temperature by the heater and stirred by the fan **213** (for example, rotating at 1500 rpm) so that the steel component loaded into the gas guide tube **222** is subjected to the nitriding treatment.

[0068] FIG. **4** is a process diagram of an embodiment of the nitriding treatment method according to the present invention in a case wherein the thermal processing furnace **201** shown in FIG. **3** is used.

[0069] In the example shown in FIG. **4**, after a steel component (work) has been loaded into the gas guide tube **222**, the inside of the retort **221** is heated to 550° C. During a former half of this heating step, an N_2 gas is introduced at a constant flow rate of 40 (L/min). During a latter half of this heating step, an NH_3 gas is introduced at a constant flow rate of 40 (L/min).

[0070] Thereafter, a two-stage nitriding treatment is performed. Specifically, at first, for example, a value of 1.500 (an example of a value within a range of 0.300 to 10.000) is employed as a first nitriding potential, and a first nitriding treatment step is performed at a temperature of 550° C.

[0071] As described above, it is known that a nitriding potential K_N is represented by the following formula using $P(NH_3)$ which is a partial pressure of the NH_3 gas and $P(H_2)$ which is a partial pressure of the H_2 gas.

$$K_N = P(NH_3)/P(H_2)^{3/2}$$

[0072] In the first nitriding treatment step, $P(NH_3)$ i.e. a partial pressure of the NH_3 gas in the gas guide tube **222** or $P(H_2)$ i.e. a partial pressure of the H_2 gas in the gas guide tube **222** is measured (alternatively, a partial pressure of the NH_3 gas in the exhaust gas or a partial pressure of the H_2 gas in the exhaust gas may be measured). Then, the introduction amounts (flow rates) of the process gases are subjected to a feedback control in such a manner that a nitriding potential calculated from the measured value is brought into the vicinity of the first nitriding potential, which is a target nitriding potential.

[0073] In the example shown in FIG. **4**, $P(H_2)$ i.e. a partial pressure of the H_2 gas in the gas guide tube **222** is measured by a heat conduction type H_2 sensor (not shown), the measured value is analyzed online (so that a nitriding potential is calculated from the measured value), and the introduction amounts (flow rates) of the process gases are subjected to a feedback control. Specifically, the introduction amount (flow rate) of the NH_3 gas is increased or decreased while an AX gas is introduced at a constant flow rate of 20 (L/min). In this case, the total amount of the two gases is also increased or decreased.

[0074] In the example shown in FIG. **4**, the first nitriding treatment step is performed for 240 minutes. Thereby, a nitride compound layer consisting of a γ' phase, or an ε phase, or mixture of a γ' phase and an ε phase, is generated in the steel component.

[0075] Subsequently, for example, a value of 0.300 (an example of a value within a range of 0.253 to 0.600) is employed as a second nitriding potential, and a second nitriding treatment step is performed at a temperature of 550° C.

[0076] In the second nitriding treatment step as well, $P(NH_3)$ i.e. a partial pressure of the NH_3 gas in the gas guide tube **222** or $P(H_2)$ i.e. a partial pressure of the H_2 gas in the gas guide tube **222** is measured. Then, the introduction amounts (flow rates) of the process gases are subjected to a feedback control in such a manner that a nitriding potential calculated from the measured value is brought into the vicinity of the second nitriding potential, which is a target nitriding potential.

[0077] In the example shown in FIG. **4**, $P(H_2)$ i.e. a partial pressure of the H_2 gas in the gas guide tube **222** is measured by the heat conduction type H_2 sensor (not shown), the measured value is analyzed online (so that a nitriding potential is calculated from the measured value), and the introduction amounts (flow rates) of the process gases are subjected to a feedback control. Specifically, the introduction amount (flow rate) of the NH_3 gas is increased or decreased while the AX gas is introduced at a constant flow rate of 30 (L/min). In this case, the total amount of the two gases is also increased or decreased.

[0078] In the example shown in FIG. **4**, the second nitriding treatment step is performed for 60 minutes. Thereby, a γ' phase is deposited in the nitride compound layer.

[0079] After the second nitriding treatment step has been completed, a cooling step is performed. In the example shown in FIG. **4**, during a former half of the cooling step (until about 400° C.), the same control as in the second nitriding treatment step is performed for the introduction amounts of the process gases. That is to say, the introduction amount (flow rate) of the NH_3 gas is increased or decreased while the AX gas is introduced at a constant flow rate of 30 (L/min). During a latter half of the cooling step (about 400° C. to 100° C.), the N_2 gas is introduced at a constant flow rate of 20 (L/min). After the cooling step has been completed, the furnace lid **212** is opened, and the case **20** that contains the steel component is unloaded from the gas guide tube **222**.

(Structural Example of Horizontal Type Thermal Processing Furnace)

[0080] FIG. **5** is a schematic view showing a structure of a horizontal type thermal processing furnace to be used for a nitriding treatment method according to the present invention.

[0081] A horizontal type thermal processing furnace is basically a furnace in which a pit type thermal processing furnace is oriented horizontally. However, as shown in FIG. **5**, the fan **213** and the fan motor **214** may be provided on a wall surface of the furnace wall **211** facing the furnace lid **212**, instead of on the furnace lid **212**.

[0082] The other structure of the horizontal type thermal processing furnace is substantially the same as the pit type thermal processing furnace explained with reference to FIG. **3**.

(Operational Example of Horizontal Type Thermal Processing Furnace)

[0083] In the horizontal type thermal processing furnace as well, the furnace lid **212** is opened, and the case **20** that contains the steel component is loaded into the gas guide tube **222**. After the steel component (the case **20** that contains the steel component) has been loaded into the gas guide tube **222**, the plurality of types of process gases are introduced into the gas guide tube **222**, and the process gases are heated to a predetermined temperature by the heater and stirred by the fan **213** (for example, rotating at 1500 rpm) so that the steel component loaded into the gas guide tube **222** is subjected to the nitriding treatment.

[0084] The process diagram shown in FIG. **4** is also applicable in a case wherein the horizontal type thermal processing furnace is used. Specifically, the heating step (introduction manners of the process gases are different between a former half thereof and a latter half thereof), the first nitriding treatment step, the second nitriding treatment step and the cooling step may be performed. After the cooling step has been completed, the furnace lid **212** is opened, and the case **20** that contains the steel component is unloaded from the gas guide tube **222**.

Summary of Effects

[0085] According to the embodiments of the present invention as described above, it is possible to obtain a nitrided steel component including an iron nitride compound layer which has a γ' phase as a main element (main component) on a surface thereof, regardless of whether a batch type of thermal processing furnace is used or a one-chamber type of thermal processing furnace is used.

[0086] The steel component obtained by the respective embodiments can achieve a sufficient pitting resistance and a sufficient bending fatigue strength because a nitrogen diffusion layer and a nitride are formed in the inside thereof to reinforce the same and an iron nitride compound layer rich in a γ' phase is formed on the surface thereof.

[0087] In addition, compared with a carburizing treatment and a nitrocarburizing treatment, the nitriding treatment according to the present invention is performed at a temperature not higher than the austenite transformation temperature, so that an amount of strain is small. In addition, a quenching step, which is necessary for a carburizing treatment or a nitrocarburizing treatment, can be omitted, so that an amount of strain variation is small. As a result, a high-strength and low-strain nitrided steel member can be obtained.

(Supplementary Information about Temperature Range of Present Invention)

[0088] In the present invention, the temperature of each nitriding treatment step is 500° C. to 590° C. It is said that, when the temperature of a nitriding treatment step is higher, the productivity thereof is better. However, according to the inventor's verification, if the temperature of a nitriding treatment step is higher than 590° C., an amount (degree) of hardening is reduced and an austenite layer is formed on the surface. Thus, it is preferable that 590° C. is the upper limit. On the other hand, according to the inventor's verification, if the temperature of a nitriding treatment step is lower than 500° C., a formation speed of the nitride compound layer is slow, which is not cost effective. Thus, it is preferable that 500° C. is the lower limit.

[0089] In addition, when the difference between the temperature of the first nitriding treatment step and the temperature of the second nitriding treatment step is smaller, variation in temperature of the steel component (work) is also smaller, which can inhibit variation in nitriding quality of the steel component (work). Specifically, the temperature difference between both the nitriding treatment steps is controlled to be preferably 50° C. or less, more preferably 30° C. or less.

Examples 1-1 to 1-9 and Comparative Examples 1-1 to 1-4

[0090] For a plurality of cylindrical ring gears (whose steel types may be different), using a batch type of thermal processing furnace **1**, a two-stage nitriding treatment was performed according to the conditions of Table 1 shown in FIG. **6**.

[0091] In examples 1-1 to 1-9 and comparative examples 1-1 to 1-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same batch type of thermal processing furnace **1**.

[0092] In addition, in the first nitriding treatment step of each of the examples 1-1 to 1-9 and the comparative examples 1-1 to 1-4, three types of gases, which are an NH_3

gas, an AX gas and an N_2 gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant.

[0093] In addition, in the second nitriding treatment step of each of the examples 1-1 to 1-9 and the comparative examples 1-1 to 1-4, two types of gases, which are an NH_3 gas and an AX gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0094] In the examples 1-1 to 1-9 and the comparative examples 1-1 to 1-4, the respective steps explained with reference to FIG. **2** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0095] In Table 1, an identification method for a phase was performed based on an X-ray diffraction pattern obtained by an X-ray diffraction measurement from a surface of a steel component in accordance with a 2θ-θ scanning method (MiniFlex 600 made by Rigalku, Cu tube, 40 kV-15 mA).

[0096] In addition, in Table 1, a thickness of the compound layer was measured as a thickness of a surface compound layer from a tissue observation result of a cross section which was cut in a depth direction of the nitrided steel component. It is preferable that a thickness of the compound layer rich in the γ' phase is 4 μm to 16 μm. When it is less than 4 μm, i.e., too thin, the fatigue strength is not sufficiently improved. When it is more than 16 μm, a porous layer in the compound layer which may be an origin of fatigue crack is too thick, which deteriorates the fatigue strength.

[0097] As seen from the result of Table 1, in the control manner using the three types of gases in the batch type of thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 1-1 to 1-9.

[0098] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 1-1 to 1-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

Examples 2-1 to 2-9 and Comparative Examples 2-1 to 2-4

[0099] For a plurality of cylindrical ring gears (whose steel types may be different), using a pit type thermal processing furnace **201**, a two-stage nitriding treatment was performed according to the conditions of Table 2 shown in FIG. **7**.

[0100] In examples 2-1 to 2-9 and comparative examples 2-1 to 2-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same pit type thermal processing furnace **201**.

[0101] In addition, in the first nitriding treatment step of each of the examples 2-1 to 2-9 and the comparative examples 2-1 to 2-4, three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant.

[0102] In addition, in the second nitriding treatment step of each of the examples 2-1 to 2-9 and the comparative examples 2-1 to 2-4, two types of gases, which are an NH_3 gas and an AX gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0103] In the examples 2-1 to 2-9 and the comparative examples 2-1 to 2-4, the respective steps explained with reference to FIG. **4** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0104] In Table 2, an identification of a phase and a thickness of the compound layer were judged in the same manner as those in Table 1.

[0105] As seen from the result of Table 2, in the control manner using the three types of gases in the pit type thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 2-1 to 2-9.

[0106] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 2-1 to 2-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

Examples 3-1 to 3-9 and Comparative Examples 3-1 to 3-4

[0107] For a plurality of cylindrical ring gears (whose steel types may be different), using the batch type of thermal processing furnace **1**, a two-stage nitriding treatment was performed according to the conditions of Table 3 shown in FIG. **8**.

[0108] In examples 3-1 to 3-9 and comparative examples 3-1 to 3-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same batch type of thermal processing furnace **1**.

[0109] In addition, in the first nitriding treatment step of each of the examples 3-1 to 3-9 and the comparative examples 3-1 to 3-4, two types of gases, which are an NH_3 gas and an AX gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0110] In addition, in the second nitriding treatment step of each of the examples 3-1 to 3-9 and the comparative examples 3-1 to 3-4 as well, the two types of gases, which are the NH_3 gas and the AX gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing the introduction amount of each of the NH_3 gas and the AX gas while keeping the total introduction amount of the two types of gases constant.

[0111] In the examples 3-1 to 3-9 and the comparative examples 3-1 to 3-4, the respective steps explained with reference to FIG. **2** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0112] In Table 3, an identification of a phase and a thickness of the compound layer were judged in the same manner as those in Tables 1 and 2.

[0113] As seen from the result of Table 3, in the control manner using the two types of gases in the batch type of thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 3-1 to 3-9.

[0114] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 3-1 to 3-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

Examples 4-1 to 4-9 and Comparative Examples 4-1 to 4-4

[0115] For a plurality of cylindrical ring gears (whose steel types may be different), using a pit type thermal processing furnace **201**, a two-stage nitriding treatment was performed according to the conditions of Table 4 shown in FIG. **9**.

[0116] In examples 4-1 to 4-9 and comparative examples 4-1 to 4-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same pit type thermal processing furnace **201**.

[0117] In addition, in the first nitriding treatment step of each of the examples 4-1 to 4-9 and the comparative examples 4-1 to 4-4, two types of gases, which are an NH_3 gas and an AX gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

[0118] In addition, in the second nitriding treatment step of each of the examples 4-1 to 4-9 and the comparative examples 4-1 to 4-4 as well, the two types of gases, which are the NH_3 gas and the AX gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing the introduction amount of each of the NH_3 gas and the AX gas while keeping the total introduction amount of the two types of gases constant.

[0119] In the examples 4-1 to 4-9 and the comparative examples 4-1 to 4-4, the respective steps explained with reference to FIG. **4** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0120] In Table 4, an identification of a phase and a thickness of the compound layer were judged in the same manner as those in Tables 1 to 3.

[0121] As seen from the result of Table 4, in the control manner using the two types of gases in the pit type thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 4-1 to 4-9.

[0122] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 4-1 to 4-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

Examples 5-1 to 5-9 and Comparative Examples 5-1 to 5-4

[0123] For a plurality of cylindrical ring gears (whose steel types may be different), using a pit type thermal processing furnace **201**, a two-stage nitriding treatment was performed according to the conditions of Table 5 shown in FIG. **10**.

[0124] In examples 5-1 to 5-9 and comparative examples 5-1 to 5-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same pit type thermal processing furnace **201**.

[0125] In addition, in the first nitriding treatment step of each of the examples 5-1 to 5-9 and the comparative examples 5-1 to 5-4, two types of gases, which are an NH_3 gas and an AX gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

[0126] In addition, in the second nitriding treatment step of each of the examples 5-1 to 5-9 and the comparative examples 5-1 to 5-4 as well, the two types of gases, which are the NH_3 gas and the AX gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing the introduction amount of the one of the NH_3 gas and the AX gas while keeping the introduction amount of the other of the NH_3 gas and the AX gas constant.

[0127] In the examples 5-1 to 5-9 and the comparative examples 5-1 to 5-4, the respective steps explained with reference to FIG. **4** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0128] In Table 5, an identification of a phase and a thickness of the compound layer were judged in the same manner as those in Tables 1 to 4.

[0129] As seen from the result of Table 5, in the control manner using the two types of gases in the pit type thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 5-1 to 5-9.

[0130] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 5-1 to 5-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

Examples 6-1 to 6-9 and Comparative Examples 6-1 to 6-4

[0131] For a plurality of cylindrical ring gears (whose steel types may be different), using a pit type thermal processing furnace **201**, a two-stage nitriding treatment was performed according to the conditions of Table 6 shown in FIG. **11**.

[0132] In examples 6-1 to 6-9 and comparative examples 6-1 to 6-4, a first nitriding treatment step and a second nitriding treatment step were performed in sequence in the same pit type thermal processing furnace **201**.

[0133] In addition, in the first nitriding treatment step of each of the examples 6-1 to 6-9 and the comparative examples 6-1 to 6-4, three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, were used, and a nitriding potential during the first nitriding treatment step was controlled to be close to the first nitriding potential (K_N), which is a target nitriding potential, by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

[0134] In addition, in the second nitriding treatment step of each of the examples 6-1 to 6-9 and the comparative examples 6-1 to 6-4 as well, the three types of gases, which are the NH_3 gas, the AX gas and the N_2 gas, were used, and a nitriding potential during the second nitriding treatment step was controlled to be close to the second nitriding potential (K_N), which is a target nitriding potential, by changing the introduction amount of the one of the NH_3 gas and the AX gas while keeping the introduction amount of the other of the NH_3 gas and the AX gas constant.

[0135] In the examples 6-1 to 6-9 and the comparative examples 6-1 to 6-4, the respective steps explained with reference to FIG. **4** were performed before and after the first nitriding treatment step and the second nitriding treatment step.

[0136] In Table 6, an identification of a phase and a thickness of the compound layer were judged in the same manner as those in Tables 1 to 5.

[0137] As seen from the result of Table 6, in the control manner using the three types of gases in the pit type thermal processing furnace, the effectiveness of the present invention wherein the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C., wherein the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C., wherein the first nitriding potential is a value within a range of 0.300 to 10.000, and wherein the second nitriding potential is lower than the first nitriding potential and is a value within a range of 0.253 to 0.600, was proved by the examples 6-1 to 6-9.

[0138] On the other hand, at a temperature within a range of 500° C. to 590° C., when the nitriding potential in the second nitriding treatment step is not higher than 0.25, the comparative examples 6-1 to 6-4 have proved that an a phase which is lower in hardness than the γ' phase was deposited, resulting in an insufficient pitting resistance and an insufficient bending fatigue strength.

DESCRIPTION OF REFERENCE SIGNS

[0139] **1** Thermal Processing Furnace
[0140] **10** Loading Section
[0141] **11** Heating Chamber
[0142] **12** Transfer Chamber
[0143] **13** Unloading Conveyor
[0144] **20** Case
[0145] **21** Door
[0146] **22** Inlet Hood
[0147] **26** Fan
[0148] **27** Intermediate Door
[0149] **30** Elevator
[0150] **32** Cooling Chamber (Oil Tank)
[0151] **35** Door
[0152] **36** Outlet Hood
[0153] **201** Thermal Processing Furnace
[0154] **211** Furnace Wall
[0155] **212** Furnace Lid
[0156] **213** Fan
[0157] **214** Fan Motor
[0158] **221** Retort
[0159] **222** Gas Guide Tube

1. A nitriding treatment method for a steel component, comprising at least two nitriding treatment steps, i.e.,

a first nitriding treatment step in which a nitriding treatment is performed to a steel component under a nitriding gas atmosphere of a first nitriding potential, and

a second nitriding treatment step in which another nitriding treatment is performed to the steel component under another nitriding gas atmosphere of a second nitriding potential lower than the first nitriding potential, after the first nitriding treatment step,

wherein

the first nitriding treatment step is performed at a temperature within a range of 500° C. to 590° C.,

the second nitriding treatment step is also performed at a temperature within a range of 500° C. to 590° C.,

the first nitriding potential is a value within a range of 0.300 to 10.000,

the second nitriding potential is a value within a range of 0.253 to 0.600,

a nitride compound layer consisting of a γ' phase, or an ε phase, or mixture of a γ' phase and an ε phase, is generated during the first nitriding treatment step, and

a γ' phase is deposited in the nitride compound layer during the second nitriding treatment step.

2. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a batch type of thermal processing furnace,

three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

3. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace,

three type of gases, which are an NH_3 gas, an AX gas and an N_2 gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

4. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a batch type of thermal processing furnace,

two types of gases, which are an NH_3 gas and an AX gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

5. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace,

two types of gases, which are an NH_3 gas and an AX gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the three types of gases constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of each of the NH_3 gas and the AX gas while keeping a total introduction amount of the two types of gases constant.

6. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace,

two types of gases, which are an NH_3 gas and an AX gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

7. The nitriding treatment method according to claim **1**,

the first nitriding treatment step and the second nitriding treatment step are performed in sequence in a same thermal processing furnace, which is a one-chamber type of thermal processing furnace,

three types of gases, which are an NH_3 gas, an AX gas and an N_2 gas, are used in the first nitriding treatment step,

a nitriding potential during the first nitriding treatment step is controlled to be close to the first nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant,

two types of gases, which are an NH_3 gas and an AX gas, are used in the second nitriding treatment step, and

a nitriding potential during the second nitriding treatment step is controlled to be close to the second nitriding potential by changing an introduction amount of one of the NH_3 gas and the AX gas while keeping an introduction amount of the other of the NH_3 gas and the AX gas constant.

8. The nitriding treatment method according to claim **1**,

wherein a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

9. The nitriding treatment method according to claim **2**,

a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

10. The nitriding treatment method according to claim **3**,

a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

11. The nitriding treatment method according to claim **4**,

wherein a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

12. The nitriding treatment method according to claim **5**,

wherein a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

13. The nitriding treatment method according to claim **6**,

wherein a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

14. The nitriding treatment method according to claim **7**,

wherein a time for which the first nitriding treatment step is performed is longer than a time for which the second nitriding treatment step is performed.

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