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PROCESS OF MANUFACTURING A REINFORCING BAR STEEL FOR PRESTRESSED CONCRETE

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ABSTRACT OF THE DISCLOSURE

A process for manufacturing an unannealed reinforcing bar steel for prestressed concrete which comprises subjecting a steel having a composition of:

0.20–0.35 weight percent carbon
0.20–2.50 weight percent silicon
0.50–3.50 weight percent manganese
1.25–4.50 weight percent chromium
(Mn+Cr)=2.75–5.00 weight percent,

the balance consisting essentially of iron by cooling it in quiet air from the hot-rolled state with the formation of bainite structure and, thereafter, either cold deforming it plastically without essential increase of tensile strength and tempering the same at a temperature in the range of 100 to 400° C. or tempering it in the temperature range between 150 and 550° C.

BACKGROUND OF THE INVENTION

Field of the invention

This invention is directed to providing a steel composition particularly useful as a bar steel for prestressed concrete to lend support to such concrete. More particularly, this invention is directed to an unannealed reinforcing bar steel to reinforce prestressed concrete provided by a process involving the selection of a suitable particular steel composition and treating the same either by cold-deforming the same plastically and subjecting it to a tempering operation carried out at a temperature between 100 and 400° C. or by tempering the same (without preceding cold-deforming) at a temperature between 150 and 550° C.

DISCUSSION OF PRIOR ART

In prestressed concrete construction, naturally-hard (as rolled) as well as cold-worked and tempered steel bars are today being used as reinforcements with minimum yield points of 60 to 90 kg./mm.^{2} and minimum tensile strengths of 90 to 110 kg./mm.^{2}. Naturally-hard (as rolled) or cold-worked and tempered bar steels of higher strengths are not used because the pearlitic steels needed for that purpose do not have sufficient toughness at higher strengths. In the case of wire of diameters up to 16 mm., quenching and subsequent tempering treatment is applied, which necessitates great expense for the equipment required for the purpose.

Bar steels of greater strength would permit higher prestressing forces with the same steel cross section, or for a given prestressing force they would permit a reduction in the number of bars needed. This would not only permit a reduction in material costs but also it would reduce the manufacturing costs and make possible more slender constructions.

The invention is aimed at accomplishing this objective, and its purpose was to manufacture an unannealed, plain or deformed reinforcing steel with a high tensile strength and a high notch ductility for prestressed concrete, in a dimensional range of from 15 to 60 millimeters diameter, with a minimum tensile strength of 120 kg./mm.^{2} and a minimum reduction of area at failure of 25%.

OBJECTS OF THE INVENTION

It is an object of the invention, therefore, to provide bar steels of improved strength which accept higher prestressing forces with the same steel cross section. Moreover, it is an object of the present invention to provide an unannealed, plain or deformed (optionally profiled) reinforcing steel for prestressed concrete having a diameter in the range of 15 to 60 mm. It is a further object of the invention to provide such an unannealed reinforcing steel for prestressed concrete having a minimum tensile strength of 120 kg./mm.^{2} and a minimum reduction of area at failure of 25%.

SUMMARY OF THE INVENTION

Broadly, this invention contemplates a process for manufacturing an unannealed reinforcing bar steel for prestressed concrete which comprises providing a steel having a composition of:

0.20–0.35 wt.-percent carbon
0.20–2.50 wt.-percent silicon
0.50–3.50 wt.-percent manganese
1.25–4.50 wt.-percent chromium
but (Mn+Cr)=2.75–5.00 wt.-percent

the balance consisting essentially of iron and cooling the same in quiet air from a temperature at or near the hot-roll end temperature and, thereafter, either cold-deforming the same plastically preferably by stretching without essential increase of tensile strength and tempering it in the temperature range of 100 to 400° C., preferably between 200 and 300° C.

In accordance with the present invention, there is provided a means for obtaining an unannealed reinforcing bar steel having a minimum tensile strength of at least 120 kg./mm.^{2} and a minimum reduction at a failure of 25%. The steel of the present inveniton may contain an amount of molybdenum up to 0.40 wt.-percent and/or a quantity of vanadium up to 0.40 wt.-percent and/or a quantity of boron up to 0.01 wt.-percent. In accordance with the present invention, it has been found that the addition of these minor quantities of molybdenum, vanadium and boron provide additional increase in strength to the steel composition so provided.

DISCUSSION OF SPECIFIC EMBODIMENTS

From the above summary of the invention, it is apparent that the steel of the present invention can be prepared in essentially two different manners starting from the initial steel composition having the required contents of carbon, silicon, manganese, chromium, iron and the required relationship between the manganese and chromium. In accordance with one method of the present invention, the steel is cooled from a temperature at or near the hot-roll end temperature in quiet air and thereafter cold-deforming the same after the steel has been cooled from the hot-rolled state and thereafter tempering at a temperature between 100 and 400° C.

Another embodiment of the present invention involves tempering the steel cooled from the hot-rolling state without cold-deforming at a temperature between 150 and

550° C. In the specification such steel is referred to as a plain steel in contrast to one which has been deformed.

Preferably, when a plain steel is prepared, in accordance with the present invention, a tempering temperature between 300 and 500° C. is used. It must be remembered, however, that time and temperature are inversely proportional to one another. Hence, if temperatures at the lower portion of the range are employed, it is generally desirable to temper for a longer period of time than would be employed had the temperature been towards the upper limit of the range.

The cold-deforming operation for the plain bars and the deformed bars is preferably carried out at a room temperature. The deformation of the steel generally by means of a cold stretching in a range from 0.1 to 1.0%, preferably in the range from 0.2 to 0.5%. The forces depend on the cross section and the yield point after cooling the steel in quiet air (as rolled condition).

By this stretching deformation the steel becomes particularly susceptible to the relatively low temperature tempering operation.

As stated above, steels of the present invention have minimum tensile strengths of 120 kg./mm.^{2}. However, such steels generally have a tensile strength between 120 and 180 kg./mm.^{2}, preferably between 135 and 160 kg./mm.^{2}. They also have a minimum reduction of area at failure of at least 25%, generally at least 40%.

The plastic deformation is done by stretching the bar so that it is elongated or extended in an amount between 0.1 and 1.0%. Preferably the deforming or stretching operation should be carried out over a period of time between 5 sec. and 3 min.

As indicated above, the process of the present invention employs a tempering in the stated temperature ranges depending upon whether an as rolled or a cold-deformed steel is desired. Generally speaking, the tempering operation should be carried out for a period of time between 1 min. and 12 hours, depending on whether it is done by continuous annealing or by batch annealing in a furnace.

Within the stated ranges of chemical composition, the strength of a 30 mm. bar, for example can be estimated on the basis of the formula

$$\sigma_B = -7 + 250 \cdot \%\ C + 13 \cdot \%\ Si + 17 \cdot \%\ Mn + 20 \cdot \%\ Cr$$

and a suitable composition can be selected accordingly. The tensile strength can be found in kg./mm.^{2} if the percentages of the alloying components are given in percentages by weight.

Preferably, the reinforcing steel has a content of

0.02 to 0.40 wt.-percent Mo
and/or 0.02 to 0.40 wt.-percent V
and/or 0.001 to 0.01 wt.-percent B.

In order to more fully illustrate the nature of the invention in the manner of practicing the same, the following examples are presented:

TABLE 1

State of a bar diameter 26.4 mm.	Kg./mm.^{2}		Percent		Reduction of area
	$\sigma_{0.2}$	σ_B	δ_5	δ_{10}	
Reinforcing steel now in common use	85.4	110	------	10.4	27.5
Reinforcing steel treated in accordance with the inv.:					
After a ½ hr. tempering at 400° C.	122	155	12.0	7.6	43
After a stretching of 0.2% and 5 min. tempering at 270° C.	128	153	13.0	8.1	42

For purposes of comparison, the mechanical characteristics of a hot-rolled, stretched and tempered reinforcing bar that is currently used (Quality St 85/105; diameter 26 mm.; data given in annual averages) have been set forth in the first line of Table 1.

In the ensuing disclosure there is shown the mechanical characteristics of a type produced by the method of the invention, the melted steel having the following chemical analysis:

0.31 wt.-percent C
0.31 wt.-percent Si
0.76 wt.-percent Mn
3.2 wt.-percent Cr
Remainder consisting essentially of iron.

The usual accompanying elements were present.

As Table 1 shows, the reinforcing bar made by the process of the invention attains considerably better strength values for equal toughness characteristics. The desired mechanical characteristics can be achieved either by a tempering operation e.g., one half hour at 400° C. bar steel with 26.4 mm. diameter or by stretching followed by tempering.

The yield point can be adjusted to the desired value by varying the stretch percentage. The tempering operation that follows may be performed at 270° C. over a period of between 5 and 60 minutes, although its effect does not vary appreciably from that achieved by a tempering time of 5 minutes. In the case of tempering below 200° C. the tempering time would, in a known manner, have to be extended; if the tempering were performed at temperatures above 300° C. the time could be less than 5 minutes.

Experiments relating to notch impact toughness also show the advantages of the reinforcing steel manufactured by the method of the invention. These tests were performed on specimens that were notched on one side.

As it will appear from a comparison of the mechanical characteristics listed in Table II, the notching of the steel used at the present time produces a slight loss of tensile strength plus a great loss of elongations at rupture and uniform elongation.

The reduction of area at failure also drops virtually to zero. The above-described reinforcing steel made in accordance with the invention, however, shows no loss of tensile strength and uniform elongation. The values of elongations and reduction of area at rupture are much better than in the steel used at the present time.

The notch was made by machining; the notch depth was 0.5 mm., the notch radius was 0.25 mm. and the angle of the flanks was 45°.

TABLE II

	New steel, 30 mm. diameter		Steel used at the present time, 32 mm. diam.	
	Plain	Notched	Plain	Notched
Tensile strength σ_B (kg./mm.^{2})	154	154	112	103
Elongation at rupture δ_5 (percent)	12	6.8	10.4	ca. 2
Elongation at rupture δ_{10} (percent)	7.6	5.8	8.6	ca. 2
Uniform elongation (percent)	5.5	5.5	7.5	2
Reduction at of area rupture (percent)	42	17	30	(a)

a Too small to measure.

The tempering, preceded, if desired, by a small amount of cold deformation, can be performed preferably by passing the bars continuously through an induction heating field, or by direct electrical resistance heating. It can also be performed in a furnace, however, a longer tempering time is to be applied if it is necessary or desirable to reduce the hydrogen content of the steel.

In the case of the steels which undergo a slight degree of plastic deformation in the unheated state prior to tempering, it may be desirable to subject the steel to a heat treatment for the reduction of its hydrogen content prior to the cold working process.

The steel of the invention, in spite of the sparing use of alloying elements and its uncomplicated and inexpensive method of manufacture, offers an outstanding and improved combination of properties, especially in regard to tensile strength and reduction of area at rupture. Further-more, it is characterized by a very good creep resistance, which is especially important for use in prestressed concrete construction in which it is subject to long-term high tensile stress.

From the above it is seen that the simple, inexpensive process of the present invention provides steels having a minimum tensile strength of 120 kg./mm.^{2} and a minimum reduction of area at failure of 25% and upwardly of about 43%. Additionally, the properties with respect to the notched steel are compared favorably with steels prepared by prior art processes. Note that such notched steels have substantially better elongation at rupture and compare quite favorably to prior art steels which have not been notched. The reduction of area at rupture for a notched steel is 17%, whereas the same value for the notched steel of the prior art is too small to measure. Thus, it is seen that the inexpensive process of the present invention provides steels which are substantially superior in elongation, tensile strength and reduction of rupture to those heretofore provided. Such has been provided with such steels even though the diameter is slightly less.

The terms and expressions used herein have been used as terms and expressions of description and not of limitation, as there is no intension, in the use of such terms and expressions, of excluding any equivalents, or portions thereof, as various modifications and departures will become apparent to one skilled in the art from the above disclosure.

The expression "unannealed steel" in this description means that the steel is not subjected to a heat treatment consisting of hardening the steel by quenching it from hardening temperatures and subsequently tempering of the quenched (hardened) steel.

The symbols used in this specification mean:

$\sigma_{0.2}$ kg./mm.^{2}=yield strength at a yield stress in kg./mm.^{2} at which the steel exhibits a deviation of 0.2% from proportionality of stress and strain;

σ_B kg./mm.^{2}=tensile strength in kg./mm.^{2} the maximum stress at fracture (breaking) in tensile test;

δ_5 percent and δ_{10} percent=elongation measured after rupture of the specimen within the gauge length expressed in percentages of the original gauge length, the latter being 5 or 10 times the diameter of the specimen;

"Reduction of area at failure"=the difference, expressed as a percentage of the original cross-sectional area, between the original cross-sectional area of a tensile test specimen and the minimum cross-sectional area after complete separation;

"Plain bar" means a bar with a smooth surface, whereas "deformed bar" means a bar equipped with ribs or the like on its surface.

What is claimed is:

1. A process for manufacturing an unannealed high strength and high notch ductility plain or deformed reinforcing bar steel in a diameter range of 15 to 60 mm. with a minimum tensile strength of 120 kg./mm.^{2} and a minimum reduction of area at failure of 25% for prestressed concrete which comprises providing a steel having a composition comprising

0.20–0.35 weight percent carbon
0.20–2.50 weight percent silicon
0.50–3.50 weight percent manganese
1.25–4.50 weight percent chromium
but (Mn+Cr)=2.75 to 5.00 weight percent,

the balance consisting essentially of iron and hot rolling it followed by immediate cooling from a temperature at or near the hot roll temperature in quiet air, thereafter, either cold-deforming the same plastically without substantial strength increase and thereafter tempering it at temperatures between 100 and 400° C. or tempering the same at a temperature between 150 and 550° C.

2. A process according to claim 1 wherein the steel composition contains up to 0.40 weight percent molybdenum.

3. A process according to claim 1 wherein the steel composition contains up to 0.40 weight percent vanadium.

4. A process according to claim 1 wherein the steel composition contains up to 0.01 weight percent boron.

5. A process according to claim 1 wherein the steel is tempered (without cold-deformation) at a temperature between 300 and 500° C.

6. A process according to claim 1 wherein said steel is stretched to accomplish the plastic deformation.

7. A process according to claim 5 wherein the steel is thereafter tempered at a temperature between 200 and 300° C.

8. A process according to claim 1 wherein the steel composition is selected to satisfy the formula

$$\sigma_B = -7 + 250 \cdot \%C + 13 \cdot \%Si + 17 \cdot \%Mn + 20 \cdot \%Cr.$$

9. A process according to claim 1 wherein the tempering is carried out over a period of time between one minute and twelve hours, wherein the shorter times belong to continuous annealing and the longer time batch annealing.

10. A process according to claim 1 wherein the steel undergoes a hydrogen effusion treatment prior to any tempering operation wherein the steel is maintained at an elevated temperature for a period of time sufficient to effect hydrogen removal.

11. A process according to claim 2 wherein the steel composition contains between 0.02 and 0.40 weight percent molybdenum.

12. A process according to claim 3 wherein the steel composition contains between 0.02 and 0.40% vanadium.

13. A process according to claim 4 wherein the steel composition contains between 0.001 and 0.01 weight percent boron.

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