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(54) **Title**: IMPROVED REINFORCING BAR AND METHOD FOR MANUFACTURING THE SAME

(57) **Abstract**: Disclosed are an improved reinforcing bar and methods for manufacturing the same. The improved reinforcing bar is made from a high strength material, and has a circular or oval or elliptical cross section and deformation of the axis in a single plane or in multiple planes. The methods for manufacturing the improved reinforcing bar include a hot working process and a cold working process. The undulating /wavy bar with axis deformation can improve the anchorage of the bar in concrete and the bond strength without comprising any surface modifications. The amplitude and pattern of axis deformation of the bar can avoid stress concentration and its ill effects.



FIGURE 4

WO 2011/107848 A2

AN IMPROVED REINFORCING BAR FOR ENHANCEMENT OF THE LIFE SPAN OF REINFORCED CONCRETE STRUCTURES

FIELD OF THE INVENTION

The present invention relates to an improved reinforcing bar (REBAR) for the enhancement of the life span of reinforced concrete, reinforced concrete structures and constructions as well as reinforced concrete elements without the need for any surface treatment or surface protection to REBAR or addition of admixture in concrete or without any other special provision or effort following the making/manufacturing of REBAR where the rebar, even when made of high strength steel or any other material, has a plain surface but with a deformed axis for use in all concrete constructions. More particularly, the invention relates to the development of a new concept in the shape and axis/surface configuration of REBAR for use in concrete constructions, and a method of manufacturing the said improved reinforcing bar which shall have a plain surface (i.e., without any surface lugs/protrusions or indentations).

BACKGROUND OF THE INVENTION

Concrete is a material that is very strong in compression, but relatively weak in tension, flexure, shear and torsion. To compensate for these shortcomings or imbalance in concrete's behavior, REBAR is used in concrete structures and other reinforced concrete constructions.

The concept of reinforced concrete was initiated by Jean Louis Lambot in 1850 and the first reinforced concrete roof was built by Francois Coignet in 1853.

While any material with high tensile strength could conceivably be used to reinforce concrete, steel, with a modulus of elasticity sufficiently higher than that of concrete and a coefficient of thermal expansion closely matching that of concrete, is ideal for use as REBAR in reinforced concrete construction. Steel has also the advantages of its easy availability and relatively less cost.

The concept of provision of deformations on rebars in the form of indentations or protrusions was introduced by W E Ward in 1874 and Hyatt in 1875.

In the beginning, steel reinforcing elements were generally in the form of nets, expanded metal, wires, structural sections, plates, etc. Today, the steel reinforcing elements are mostly in the form of rods or bars. In the context of the present invention, the interest lies in REBARs in the form of steel rods/bars as well as reinforcing bars of other suitable materials.

As far as steel REBARs are concerned, in the beginning, when reinforced concrete with REBARs started becoming a common medium of construction, it used to be made of mild steel in the form of plain round bars (Figure 2) with an arbitrarily selected yield strength of 250 N/mm^2 and an ultimate tensile strength not exceeding 340 N/mm^2 for the material. In India, medium tensile steel (ultimate tensile strength of not less than 540 N/mm^2) REBARs were officially introduced with the publication of IS:432 (Part 1) in 1982. However, important changes were already initiated and cold twisted deformed (CTD) circular rebars with a proof stress of 420 N/mm^2 (Grade Fe 415) were introduced in India in 1967. CTD bars constitute a special form of high strength deformed (HSD) or high yield strength deformed (HYSD) bars (Figure 3). A typical CTD bar is shown in Figure 3A.

By about 1970, CTD rebars of Grade Fe 415 replaced the classical plain mild steel rebars by about 50 percent in India. By about 1978 CTD bars of Fe 500 was introduced. Thermo-mechanically treated (TMT) rebars were developed around the world in the early 1980s, gradually replacing CTD bars. In India, TMT bars were first introduced in 1992. Today TMT bars form the most common form of REBARs, and the yield stress has gone up to 600 N/mm^2.

The REBARs of higher strength steel (yield stress or 0.2 percent proof stress of 415 N/mm^2 and above), which started replacing plain round bars of mild steel in the 1960's, were given surface deformations as with higher forces in high strength bars (compared to forces in medium strength or lower strength bars of the same diameter or cross-section), it was felt necessary to restrict the longitudinal movement of the bars relative to the surrounding concrete by increasing the bond capacity between rebar and surrounding concrete or increasing the resistance to tensile or pull-out forces without any substantial increase in the anchor or development length of bars. Bars were thus provided with surface

deformations in the form of surface lugs or protrusions. Generally, longitudinal ribs are also present on the surface of the bars (Figures 3 and 3A). Such ribbed bars (i.e. bars with surface deformations) resisted tensile forces partly by adhesion, partly by frictional resistance and partly by interlocking or wedge action.

The consequences of using steel rebars with surface deformations in the form of lugs, protrusions, etc. became grave as reinforced concrete structures, constructions and elements, constructed with such rebars, reached states of distress much earlier than did similar constructions of earlier periods where the bars did not have surface deformations.

Central Public Works Department, Government of India, Technical Circular 1/99, Memo No. CDO/DE(D)/G-291/57 dated 18/02/1999 (issued by Chief Engineer (Designs), Nirman Bhawan, New Delhi - 110 011) reported in its technical Circular 1/99 that the recent constructions in concrete were showing signs of distress within a couple of years of their completion while work as old as 50 years provided adequate service.

Swamy, R. N., ("Infrastructure regeneration: the challenge of climate change and sustainability — Design for strength or durability?", The Indian Concrete Journal. Vol. 81, No. 7, July 2007) suggests that the most direct and unquestionable evidence of the last two/three decades on the service life performance of present constructions and the resulting challenge that confronts us is the alarming and unacceptable rate at which the infrastructure systems all over the world are suffering from deterioration when exposed to real environments. Swamy also lamented the unacceptably poor performance of reinforced concrete structures in spite of the tremendous advances that have been made in understanding of the science engineering and mechanics of materials and structures.

The crisis, created by the poor performance of reinforced concrete structures, is an international one. The above remarks by Swamy are based more on his observations of the performance of concrete structures. It needs to be noted here that the present concrete constructions are with steel rebars with surface deformations whereas the durable concrete structures of earlier periods were constructed with bars without any such deformations.

Papadakis, V. G., Vayenas, C. G., and Fardis, M. N., ("Physical and Chemical Characteristics Affecting the Durability of Concrete," ACI Materials Journal, American

Concrete Institute, March - April, 1991) discloses in their paper in 1991 that the previous two decades had seen a disconcerting increase in examples of the unsatisfactory durability of concrete structures, specially reinforced concrete ones.

It is again noted here from the period of observation that the unsatisfactory durability refers to unsatisfactory performance of reinforced concrete constructions with high strength rebars of steel with surface deformations and the unsatisfactory performance started showing up with the use of HSD rebars.

There were cases where coarse aggregates, supported by lugs or protrusions on HSD rebars, prevented intimate contact between concrete and rebars with surface deformations to the detriment of the health of reinforced concrete structures.

Mohammed, T. U., Otssuki, N., and Hisada, M., ("Corrosion of Steel Bars with respect to Orientation," ACI Materials Journal, American Concrete Institute, March - April, 1999) too concluded on the basis of tests for specific performance that due to the formation of gaps, the bottom part of horizontal steels showed significant macrocell and microcell corrosion and deformed bars corroded more than plain bars.

Kar, Anil K., ("Concrete structures — the pH Potential of Cement and Deformed Reinforcing Bars," Journal of The Institution of Engineers (India), Civil Engineering Division, Vol. 82, June 2001) explained that besides the presence of yield strains and stresses all over the surface in the case of CTD rebars, the surface strains and stresses in the case of other HSD rebars too would or could reach yield levels under service load conditions due to the phenomenon of stress concentration as a result of the presence of lugs or protrusions on the surface of HSD or high yield strength deformed (HYSD) rebars. Kar further explained that once the stresses/strains of steel bars would reach yield stress/strain levels, such bars would corrode uncontrollably.

It is thus an inherent characteristic of HSD rebars that such rebars with surface lugs or protrusions will corrode early and concrete constructions with such bars will reach states of distress early.

Kar, Anil K., ("Deformed reinforcing bars and early distress in concrete structures," Highway Research Bulletin, Highway Research Board, Indian Roads Congress, Number 65,

December 2001) observed on the basis of a survey on several randomly selected buildings and bridges in the public domain in Kolkata that, compared to concrete structures with plain round bars of mild steel, concrete structures with CTD rebars would become distressed early, no matter what the type of cement was.

Furthermore, the above mentioned prior art journals and Moskvin, V. [edited by, translated from the Russian by V. Kolykhmatov, "Concrete and Reinforced Concrete Deterioration and Protection," 1990, English translation, original Mir Publishers, Moscow, 1983) disclosed that the durability of concrete structures with HSD and HYSD rebars of steel was an order of magnitude less than the durability of structures with plain round bars of mild steel.

The finding of Kolykhmatov is due to the fact that once the surface strains and stresses reach or go beyond yield, as it does in the case of HSD bars, and more particularly in the case of CTD bars, the surface elements of such bars become unstable and such bars with unstable surfaces cannot be passivated by the alkaline pore water inside concrete.

The CTD bars can be characterized as bars with surface deformations (Figure 3) as well as locked-in manufacturing stresses beyond yield all over the surface due to twisting/straining beyond yield at a cold state as a part of the manufacturing process.

Kar, Anil K., ("Waterproofing of Structures : Challenges and Solutions," New Building Materials & Construction World, Vol. 11, Issue-10, 2006) has further shown with examples and photographs that, soon after cold twisting, steel rebars with surface deformations will start corroding at a fast rate.

This demonstrates the strong influence of high stresses, specially stresses above yield, on causing corrosion in rebars of steel.

The above mentioned prior art documents show that the problem of early decay and distress in reinforced concrete structures has much to do with the use of high strength rebars (of steel) with surface deformations (HSD) (Figure 3) than with the use of any particular type of cement or any worsening of the environment over the years. Worst among the HSD rebars is the CTD rebar.

Besides the problem, associated with the use of HSD rebars of steel, the problem of early distress in concrete structures is particulary severe where such structures are exposed to salt water, as is the case of bridges built in areas where salt is applied to roadways in winter, or of concrete structures of all types in coastal regions.

Epoxy-coated, galvanized or stainless steel rebars with surface deformations have been attempted in these situations at greater initial expense, but Kar, Anil K., ("FBEC rebars must not be used," The Indian concrete Journal, Vol. 78, No.1, January 2004) explained why at added cost epoxy coated steel rebars did not give any assurance of added life span to reinforced concrete structures. Furthermore, the use of epoxy coated rebars could prevent bond between rebar and surrounding concrete and it could make reinforced concrete structures specially vulnerable under vibratory load conditions as it would be during earthquakes.

Kar, Anil K., and Vij, Satish K., ("Enhancing the Life Span of Concrete Bridges", New Building Materials & Construction World, Vol. 15, Issue-6, December 2009) have explained that by itself, costly zinc coating too cannot effectively protect HSD rebars against corrosion. Manufacturers have thus proposed HSD rebars with a combination of zinc coating followed by epoxy coating. But epoxy coatings on rebars prevent or diminish bond with concrete, thereby endangering the life of concrete structures under vibratory loading conditions. Costly stainless steel, though less prone to corrosion, suffers from poor bond with surrounding concrete.

Fiber-reinforced polymer rebar is now also being used in high-corrosion environments. It is available in many forms, from spirals for reinforcing columns, to the common rod, to meshes and many other forms. Most commercially available rebars are made from unidirectional glassfibre reinforced thermoset resins. However, such rebars are very expensive. Besides higher cost and inadequate resistance to fire, fibre reinforced polymer bars may suffer from basic disadvantages of inadequate modulus of elasticity and poor bond between such bars and the surrounding concrete.

US 4,329,825 discloses a reinforcing bar support for joining concrete structures, having a hollow body of prismatic shape and formed by a front part and by a cover part. The

front part features a front side scheduled to be installed in the concreted main wall, two longitudinal narrow sides and two cross sides. The sides are so designed that the cover part can be clamped to the front part and released therefrom. The front side is provided with a longitudinal center groove and equidistant cross grooves, with the cross grooves used for marking holes to be drilled later, which holes are scheduled to receive the leg ends of the reinforcing bars.

US 5,468,524 discloses the casting of stronger and more precise steel reinforced concrete members and also to facilitate the formation and field joining of such members there is provided a bar splice which comprises a generally cylindrical sleeve open at one end to form an axially elongated chamber to receive a steel reinforcing bar telescoped therein, and provided with internal threads at the other end whereby a threaded bar end may be secured to the other end, and when secured sealing the other end of the chamber. The threads are preferably tapered and the chamber includes inwardly extending axially spaced annular ribs. Lateral ports are provided at each end of the chamber. The wall thickness of the chamber adjacent the threaded end of the sleeve may be increased to improve tensile capabilities. The length of the chamber is most of the splice sleeve since the threaded connection occupies little axial space.

US 4,143,986 discloses a reinforcing rod splice for connecting reinforcing rods in end to end relation including a pair of hollow steel tubes and a coupling or sleeve, the tubes being mounted on the ends of the reinforcing rods. The tubes being deformed on the inner surface to conform to the deformations on the rods and deformed on the outer surface to provide a connection for the coupling or sleeve. The coupling or sleeve having an inner surface conforming to the deformations on the outer surfaces of the tubes.

US 863959 discloses a bar for the reinforcing of concrete, artificial stone, etc for construction purposes; said bar being polygonal in cross section and having within each face thereof elevations projecting therefrom and having at the intersection of its faces elevations, diminishing in height from the longitudinal central portion to the ends thereof. However, from practical considerations, though not from adequate considerations for durability, round

bars of the types shown in Figure 3 became more popular in the case of rebars with high strength steel.

The disadvantage of the above mentioned prior art is that it was intrinsic of HSD rebars (Figure 3) that such bars would corrode early, as among other detrimental aspects : (a) the presence of deformations on the surface of such rebars of steel cause nominal strains and stresses in such bars to rise and go past yield locally in a phenomenon known as stress concentration, (b) cold twisted deformed (CTD) bars, the worst among HSD rebars, would be strained and stressed beyond yield all over the surface even as a part of the manufacturing process, (c) high strains/stresses, particularly yield strains/stresses or stresses beyond yield, would lead to (i) slippages at intergrain faces of metal, and (ii) unbounded corrosion, (d) HSD rebars, particularly CTD bars, with surface strains/stresses beyond yield, cannot be passivated inside concrete even if the pH level of its pore water would be above 12.0, and (e) exposure of the unstable and thus the non-passivated and unprotected surface of steel rebar, with surface strains/stresses beyond yield, to the agents of corrosion, viz., moisture, oxygen, chlorides, etc. (even though the bars will be inside concrete), would cause corrosion fairly early compared to cases of structures with plain round bars of mild steel where the strains and stresses on the surfaces of bars would be less than yield strains and stresses and where the bars inside concrete will consequently be passivated.

There can thus be no scope for any doubt that the use of high strength steel rebars with surface deformations, as opposed to bars with plain surface, is one of the prime causes of early distress in concrete structures of recent decades.

Thus, for making reinforced concrete structures and other constructions durable, there is a need (a) to provide an improved product that is an improved reinforcing bar of steel which will be made of high strength or any other grade of steel which will be permissible for use in reinforced concrete construction and yet which, even without surface treatment or surface protection, would not corrode easily like CTD and other HSD rebars of steel would do, and (b) a process to manufacture the said product, where the process to manufacture the said product can be implemented without any or without much additional effort, compared to what is required to make conventional HSD rebars.

OBJECTS OF THE INVENTION

The basic object of the present invention is to overcome the disadvantages of the prior art.

Another object of the present invention is to provide an improved reinforcing bar which is capable of enhancing the life span of reinforced concrete structures, constructions, elements, steel-concrete composites, etc. without having to make any or much of any additional effort or without having to incur an additional expense, viz., provision of surface coatings to rebars or galvanizing of rebars, use of admixtures in concrete, provision of surface protection to concrete structures, etc.

Another object of the present invention is to provide an improved bar which has a plain surface and a deformed axis.

Yet another object of the present invention is to manufacture an improved bar with mild steel or medium tensile steel or high strength steel or any other steel or of any other material that will have no surface lugs/protrusions, indentations or surface deformities but which will have a deformed axis; the bar can have any cross section but it shall have no sharp or local surface feature.

A further object of the invention is to provide a REBAR of steel which, in the absence of local surface features, does not have enhancement of stresses and strains locally and which does not corrode as quickly as rebars with surface protrusions or indentations do.

Yet another object of the present invention is to provide an improved reinforcing bar which is cost effective, simple in configuration or concept and which is easy to manufacture and use.

And another object of the present invention is to provide a process for the manufacture of the improved reinforcing bar.

SUMMARY OF THE INVENTION

The present invention relates to an improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures comprising:

a high strength material;

a circular or oval or elliptical cross section of said bar;

deformation of the axis of the bar in one or more planes.

A method for manufacturing of an improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures by hot working comprising steps of:

making of billet for high strength bar of steel;

reheating the said billet;

rolling the said billet in a rolling mill and making bars of the desired size and shape (cross-section);

deforming the said bars using gear rollers or by any other device or means;

optionally providing any heating/cooling treatment;

cutting bars into desired lengths using shears

cooling of said bars in a cooling bed.

Further, a method for manufacturing of an improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures by cold working comprising steps of:

making of billet for high strength bar of steel;

reheating the billet;

rolling the said billet in a rolling mill to make bars of the desired size and shape (cross-section);

cutting bars into desired lengths using shears;

optionally cooling of said bars in a cooling bed;

deforming the said bars using gear rollers or by any other device or means;

optional annealing to relieve residual stresses.

BRIEF DESCRIPTION OF THE ACCOMPANYING FIGURES

Figure 1. Illustrates some of many possible cross sections of REBARs without any surface lugs or protrusions and without any sharp or local features according to present invention.

Figure 2. Plain round rebars, with straight line configuration, which were commonly used before the introduction of medium tensile and high strength steel REBARs with surface deformations (Figures 3 and 3A).

Figure 3. Typical high strength REBARs with surface deformations but of straight line configuration, which replaced plain round bars of mild steel and medium tensile steel (Figure 2), starting the 1960's and 1970's.

Figure 3A. Typical cold twisted deformed (CTD) rebar with lugs and protrusions on the surface and stresses beyond yield on the entire surface.

Figure 4. Surface view (elevation) of one end of a rebar with a deformed axis configuration, but without any surface lug or protrusion or indentation according to present invention.

Figure 5. Surface elevation of partial lengths of some bars according to present invention.

Figure 6. Achieving deformed configuration of bar — a schematic arrangement.

Figure 7. A generalized process diagram for achieving (by hot working) deformed configuration of bars without any controlled cooling or thermo-mechanical treatment.

Figure 8. A generalized process diagram for achieving (by hot working) deformed configuration of bars with optional controlled cooling (thermo-mechanical treatment).

Figure 9. A generalized process diagram for achieving (by cold working) deformed configuration of bar which had undergone optional controlled cooling (thermo-mechanical treatment).

Figure 10. A generalized process diagram for achieving (by cold working) deformed configuration, followed by annealing, where desired.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed at a reinforcing bar (REBAR) of steel of any desired type and grade or of any other suitable material which is having a deformed axis but plain surface for use as reinforcing element in reinforced concrete, reinforced concrete

elements, reinforced concrete structures, composite construction of steel and concrete and in any other concrete construction where reinforcing bars of steel or of any other suitable material are required to be used. The bar has a plain surface and a deformed axis for use in all concrete constructions wherever there are requirements for reinforcement and/or whichever construction requires the application of the principles of reinforced concrete design and construction. (Figures 4-6). According to the present invention a plain bar is provided with a deformed axis which makes the bar look undulating/wavy in perspective view. The amplitude and pattern as well as the distance between successive peaks of the said undulations may be varied such that high/increased gripping capacity, i.e., bond or resistance to pull-out is maintained without compromising in any significant way the overall linear characteristic of the bar and yet avoiding stress concentration and its ill effects, e.g., early corrosion in the case of CTD and other HSD rebars of steel. The preferred, but not limited to, range of amplitude of deformation of the axis of the REBAR is 1 to 10 mm.

The present invention is further directed at a process to manufacture the said product where a straight line bar of a desired cross section (Figure 1) in its plastic state, e.g., hot Process working temperature of around 900°C to 1200°C in most cases of steel is passed through a set or more sets of toothed rollers/gears or through such other devices/tools to achieve a deformed configuration. (Figures 4-6).

The present invention is further directed at a process to manufacture the said product where a straight line bar of a desired cross section (Figure 1) at less than the hot working temperature of about 900°C to 1200°C (in the case of steel) is made to have a deformed shape (Figures 4-6). In such cases, stresses, which may be locked in due to processing/bending at less-than-plastic temperature, can be released, if desired, by annealing/heat treatment.

In its Clause **5.6 Reinforcement** The *Indian Standard* PLAIN AND REINFORCED CONCRETE CODE OF PRACTICE *(Fourth Revision)*, IS 456:2000 permits the use of reinforcing elements thus

a) mild steel and medium tensile steel bars conforming to IS 432 (Part 1)

b) high strength deformed steel bars conforming to IS 1786

c) hard-drawn steel wire fabric conforming to IS 1566

d) structural steel conforming to grade A of IS 2062

Steel rebars, referred to in (a) above, are amenable to improvement according to the present invention. The present invention provides a better alternative to high strength steel rebars with surface deformations, referred to in (b) above and also referred to in other national and international codes (viz., BS 4449, ASTM A615M, ASTM A706M, EN10080, Asian Model Code 1999, etc.), as according to the present invention there will not be early corrosion due to the effects of stress concentration and stress corrosion and yet there will be improved bond or enhanced resistance to slippage at the rebar-concrete interface. Furthermore, chances of loss of contact between rebar and surrounding concrete is minimized. The basic scheme to make rebars with a deformed axis, rather than with surface deformities, to enhance resistance to slippage is applicable also in case of rebars of any other material(s).

Other national, foreign, international codes, standards, guides, etc. permit the use of some or all of the different types of products which are identified in items (a) to (d) above as reinforcing elements, except that the products may conform to all or some or none of the standards IS 432 (Part I), IS 1786, IS 1566 and IS 2062.

Besides other metals and materials, the present invention relates to items (a) and (b) above, except that the invention and the products are not necessarily limited to materials or products conforming to IS 432 (Part I) or IS 1786 or to any other Indian or foreign or international code or standard or guide on REBARs for use in reinforced concrete and reinforced concrete construction.

According to the present invention, the steel (or of any other material) reinforcing bars have a circular or oval or elliptical or of any other cross section but without any sharp corners/contours or without any sharp or local features. However, instead of having a purely straight line or straight axis configuration as in prior art (Figures 2 and 3), rebars of the present invention, though maintaining the basic straight line orientation, have a non-straight line configuration. A rebar of many such possible configurations is shown in Figure 4, while a surface elevation of partial lengths of a group of such bars is shown in Figure 5.

Steel

According to one aspect of the invention there is provided a reinforcing bar (for use in reinforced concrete constructions and reinforced concrete structures) with plain surface and a deformed axis which has enhanced resistance to slippage inside concrete and which is not prone to early corrosion, as it would have happened in the case of HSD rebars (Figures 3 and 3A). Any controlled cooling/quenching (as in the thermo-mechanical treatment or TMT process) of rebar can be made following the achievement of the deformed axis (Figure 8) in which case the bar is deformed at the final stand of Rolling Mill process (Figure 6). In an alternative cold working process for the deforming of the bar, special cooling (as in the TMT process), if any, precedes the act of deforming the bar (Figures 9 and 10). Also, in the cold working process, on achieving the desired deformed shape (Figures 4 and 5) of the plain bar (Figure 1), annealing/heat treatment is optionally provided for the release of any residual stress due to the manufacturing effort (Figure 10).

Materials other than Steel

In line with the concept of rebar of linear elements with a deformed axis but plain surface, propounded here, materials other than steel, if found otherwise suitable for use as the reinforcing element, can be manufactured as shown in Figure 6 and made more useful as reinforcing element in the design and construction of reinforced concrete structures. These other materials may include glass fibre, carbon fibre, aramid, other high strength materials, made without or with the benefit of nanotechnology.

Deformed Configuration

According to the present invention, the pattern of deformation of the axis of the reinforcing element is unlimited, except that there will be no sharp bend, recess or protrusion which may act as a stress raiser leading to a significant enhancement of nominal stresses due to the phenomenon of stress concentration.

Though the deformed configuration can be achieved at a cold state, the best (for stress free or low residual stress condition) rolling/working (Figure 6 or any other arrangement), i.e. causing or effecting deformation of the axis of the steel rebar, is achieved at the hot working temperature (i.e. at plastic state), which in the case of steel is around 900^0C to 1200^0C.

The deformed configuration can be developed in different ways, one of which is the use of toothed rollers/gears (Figure 6). The axes of the rollers/gears can be horizontal or vertical or inclined to suit working conditions.

The deformation of the axis of the bar or that of any other reinforcing element can be in a single plane or in multiple planes.

The bars according to the present invention, made of high strength steel or of any other steel or of any other material and yet without any surface deformations but with a deformed axis (Figures 4-6), can be used effectively in reinforced concrete construction as the resistance of the new bars (Figures 4-6) to pull out forces, compared to resistance to similar forces on plain round bars (Figure 2) of the same size (diameter) and material but without surface deformations or without deformations of its axis, can be easily made to be 50% to 70% higher or even greater.

It is noted here that tests for resistance of HSD rebars (Figures 3 and 3A) to pull-out forces, as specified in IS:1786 and in IS:2770 and in similar codes of other countries are arbitrary in nature and details. Such arbitrariness in requirements for test for bond strength can be recognized when

a) The tests are conducted on a single bar whereas in most of real cases rebars are in close proximity to each other and tensile forces in each bar affects the performance of its neighbouring bars in terms of their resistance to pull-out or tensile forces.

b) The tests for resistance to tensile or pull-out forces are performed with rebar embedment of 5 times (Clause 4.7 and APPENDIX A of IS:1786) the diameter of the bar for rebars of different diameters and steel of different grades without any consideration of the fact that bars of the same size but of different grades of material will have different tensile forces. Furthermore, tensile forces in bars generally vary as a square of the diameter and not linearly with the diameter.

c) The bond strength is determined, from tests (Clause 4.7 and APPENDIX A of IS:1786) and yet no explicit use is made of the bond strength in design.

Thus, though the rebars of the present invention are devoid of the surface modifications of the prior art bars and even if bond strength of the rebars of the present

invention is not of similar nature to those of prior art it does not materially affect the working of the present rebars.

The plain bars of the present invention, with deformed axes but without any surface deformation in the form of lugs, protrusions, etc. (Figures 4-6), can be made of high strength steel and used as effectively as HSD rebars with surface deformations (Figure 3), and yet giving the durability of concrete structures and other constructions with plain round bars of steel (Figure 2) and the economy of concrete structures and other constructions with HSD rebars (Figure 3). In other words, the rebars or reinforcing elements according to the present invention, by virtue of preservation of the surface characteristics of plain bars (Figure 2) of the first half of the last century, have the best qualities of both plain round bars of steel and high strength rebars with surface deformations. The bars under the present invention can thus be made of the same high strength steel materials as HSD bars (Figure 3) are made of and yet these new bars can be used much more efficiently and effectively than the conventional HSD bars as the bars according to the present invention, without the shortcomings of HSD rebars (viz., stress concentration leading to stress corrosion, gaps between rebar and concrete, greater macrocell and microcell corrosion, etc.), can endow reinforced concrete structures, reinforced concrete constructions, composite constructions and other reinforced concrete elements with the life span that plain round bars of steel could do. In addition, unlike HSD rebars there will not be any need for costly surface coating to rebars of the present invention.

There are no restrictions or limits to the lengths of bars according to the present invention. Similarly, there are neither any lower nor any upper limit to bar sizes (diameter) or sizes of other reinforcing elements under the present invention, Thus, besides bars of all the sizes from 4 mm to 50 mm, as identified in Clause 5.1 of IS:1786, bars of other intermediate sizes as well as bars less than 4 mm and bars above 50 mm are amenable to and permissible according to the present invention.

Similarly, the present invention covers, besides steel rebars, rebars of other metals and materials.

According to the present invention, there is no limitation on the extent of deformation of the axis from its original straight line (Figures 4-6), except that sharp contours are

preferably avoided. Also, the axis can be deformed in a single plane or in multiple planes. However, the overall straight line orientation is maintained. There is also no upper or lower limits on the distance between two successive crests or valleys (created by the deformed shape of the rebar) as long as these reside within the workability and resistance to slippage of the bar.

Tests have shown that an amplitude or deviation of even 2-3 millimeters from the straight axis can raise the resistance of plain round bars of steel to pull out forces by 50% - 70% (Table 1). It should be possible to increase the resistance further with proper selection of the pattern and extent of deformation. For the purpose of the present invention and in due consideration of field conditions it is proposed that the deformation/departure of the axis of the bar from its normal straight line be made to be 1 mm to 10 mm.

Though steel rod (of any desired/permissible metallurgical composition, of any and all practical grades, strengths, ductility, malleability and/or any other property of intent and interest) for use in reinforced concrete structures is at the focus of this invention, the basic features of this invention cover rods, bars, plates of steel or any other material (including composites) and shape where the objective will be the avoidance of the ill effects of stress concentration and yet the achievement of high resistance to slippage or bond failure of the reinforcing elements (e.g., rebar) in a matrix of another material (e.g., concrete, mortar) or materials.

Both hot working (during plastic state of material) and cold working is possible according to the present invention.

As illustrated in figures 7 and 8 the process steps involved in case of hot working for achieving deformed configuration of bars with/without any controlled cooling or thermo-mechanical treatment (optional) are:

making of billet for high strength bar of steel, reheating the said billet, rolling the said billet in a rolling mill and making bars of the desired size and shape, deforming the said bars using gear rollers or by any other device or means, optionally providing any heating/cooling treatment as in the case of thermo mechanical treatment , cutting bars into desired lengths using shears and cooling of said bars in a cooling bed.

As illustrated in figures 9 and 10 the process steps in case of cold working for achieving deformed configuration of bars with controlled cooling or thermo-mechanical treatment followed by annealing (optional) are:

making of billet for high strength bar of steel, reheating the billet, rolling the said billet in a rolling mill to make bars of the desired size and shape, optionally providing any heating/cooling treatment as in the case of thermo mechanical treatment ,cutting bars into desired lengths using shears, cooling of said bars in a cooling bed, deforming the said bars using gear rollers or by any other device or means, optional annealing to relieve residual stresses.

Further in case of both hot and cold working to achieve deformed configuration of bars splitting tendency and other quality checks are performed in the above mentioned processes which is optional.

As a result of the present invention, providing any post-treatment is not essential when the deformation process involves hot working at a stage when the material will be in its plastic state. However, there is no bar to any post-treatment. Should it be so desired, stress relieving by annealing (in the case of cold working) or any other post treatment (e.g. controlled cooling as in thermo-mechanical treatment) can be provided.

TABLE 1. RESISTANCE TO PULL-OUT FORCES

	Material used	Amplitude of surface lug or Amplitude of axis deformation	Shape (cross section) of Bar	% of Resistance to pull out forces
Plain round surface + straight axis.	Medium strength bar of Mild steel	-	Round	100%
Deformed surface + straight axis.	High strength bar of steel	0.5 mm – 2.0 mm	Round	180%
Present invention (plain surface + deformed axis.	High strength bar of steel	1-10 mm*	Round	150% - 170%*

Note :*Figures indicate values for and from specific tests. Amplitude and plane of deformation can be changed and resistance to pull-out forces enhanced.

CLAIMS

1. An improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures comprising:
   a) a high strength material;
   b) a circular or oval or elliptical cross section of said bar;
   c) deformation of the axis of the bar in specific plane(s).
2. The bar as claimed in claim 1 wherein said deformation of axis which makes the bar look undulating/wavy with the amplitude and pattern of axis deformation as well as the distance between successive peaks of the said undulations is varied such that high/increased gripping capacity and bond or resistance to pull-out forces is maintained without compromising in any significant way the overall linear characteristic of the bar and yet avoiding stress concentration and its ill effects.
3. The bar as claimed in claim 1 wherein said deformation is in single plane or in multiple planes.
4. The bar as claimed in claim 1 wherein said bar is of circular shape.
5. The bar as claimed in claim 1 wherein said amplitude of surface or axis deformation is 1 mm to 10 mm.
6. The bar as claimed in claim 1 wherein said resistance to pull out forces is 150% to 170% compared to resistance of bars with plain surface.
7. The bar as claimed in claim 1 to 6 wherein said bar has a plain surface and a deformed axis.
8. The bar as claimed in claim 1 wherein said high strength material comprises of glass fiber or carbon fiber or aramid or other high strength materials, made without or with the benefit of nanotechnology, preferably steel.
9. A method for manufacturing of an improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures by hot working comprising steps of:

   making of billet for high strength bar of steel;

reheating the said billet;
rolling the said billet in a rolling mill and making bars of the desired size and shape;
deforming the said bars using gear rollers or by any other device or means;
optionally providing any heating/cooling treatment;
cutting bars into desired lengths using shears
cooling of said bars in a cooling bed.

10. A method for manufacturing of an improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures by cold working comprising steps of:
making of billet for high strength bar of steel;
reheating the billet;
rolling the said billet in a rolling mill to make bars of the desired size and shape;
cutting bars into desired lengths using shears;
cooling of said bars in a cooling bed;
deforming the said bars using gear rollers or by any other device or means;
optional annealing to relieve residual stresses.

11. The method of an improved bar as claimed in any of claim 9 or 10 wherein said rolling mill process is followed by quenching of said billet in case of thermo mechanical treatment.
12. The method as claimed in any of claim 9 or 10 wherein said rolling mill process is further followed by quality check of splitting tendency and other quality checks.
13. The method as claimed in claim 10 wherein said process of deformation is followed by annealing the said bar to remove or reduce built-in residual stresses by a process of gradually heating and cooling.
14. The method as claimed in claim 9 or 10 wherein said rollers/gears has horizontal or vertical or inclined axes.

15. The method as claimed in claim 9 or 10 wherein said hot working temperature in case of steel is around 900 ° C to 1200 ° C.

16. The improved reinforcing bar (REBAR) for reinforced concrete constructions and reinforced concrete structures and a method for manufacturing the same as substantially described herein with reference to accompanying drawings.

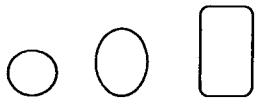

FIGURE 1

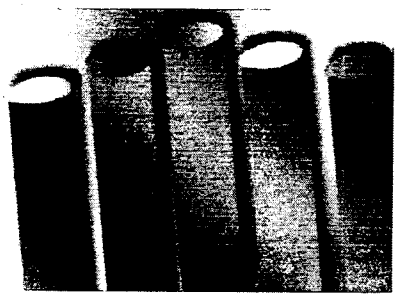

FIGURE 2

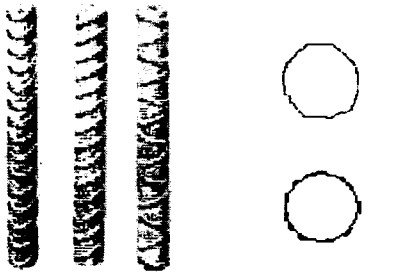

FIGURE 3



FIGURE 3A



FIGURE 4



FIGURE 5

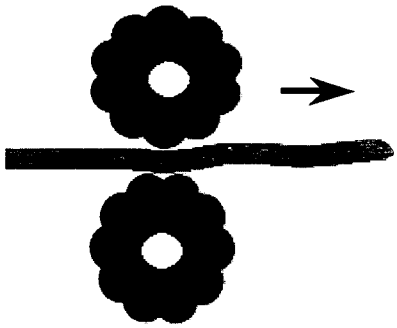

FIGURE 6

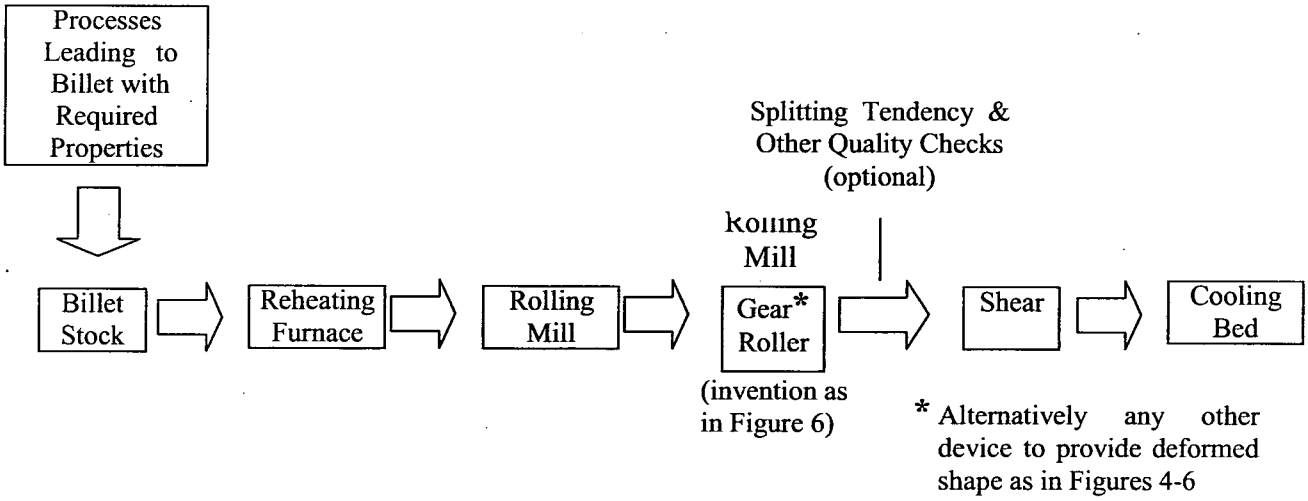

FIGURE 7

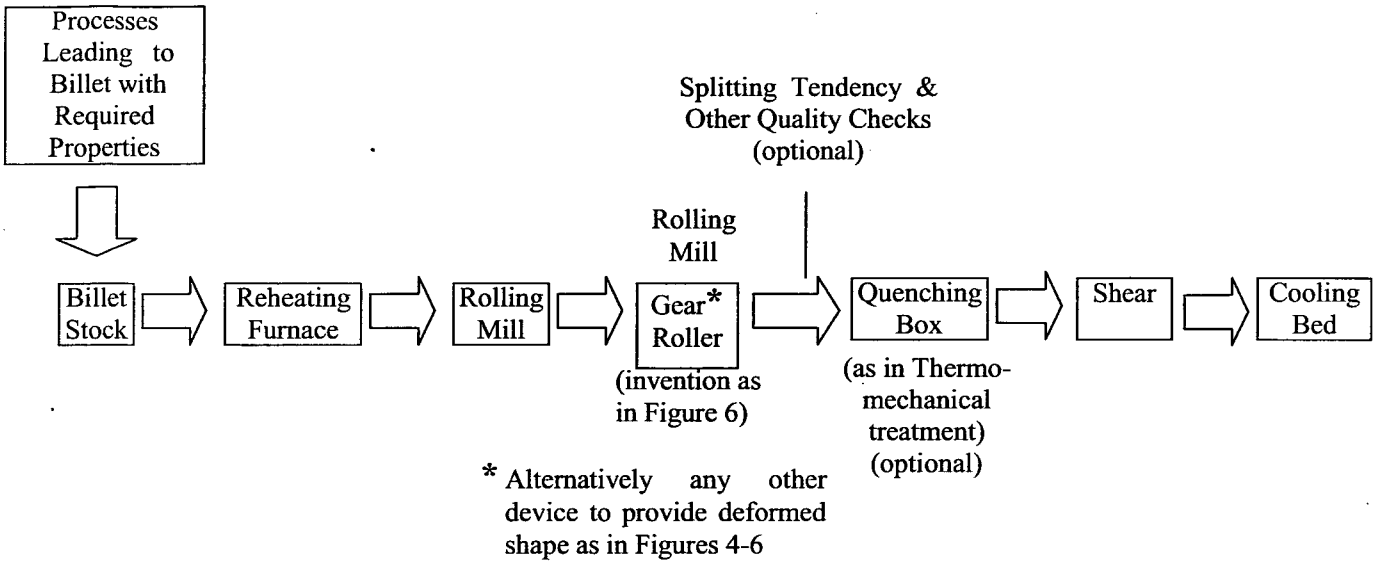

FIGURE 8

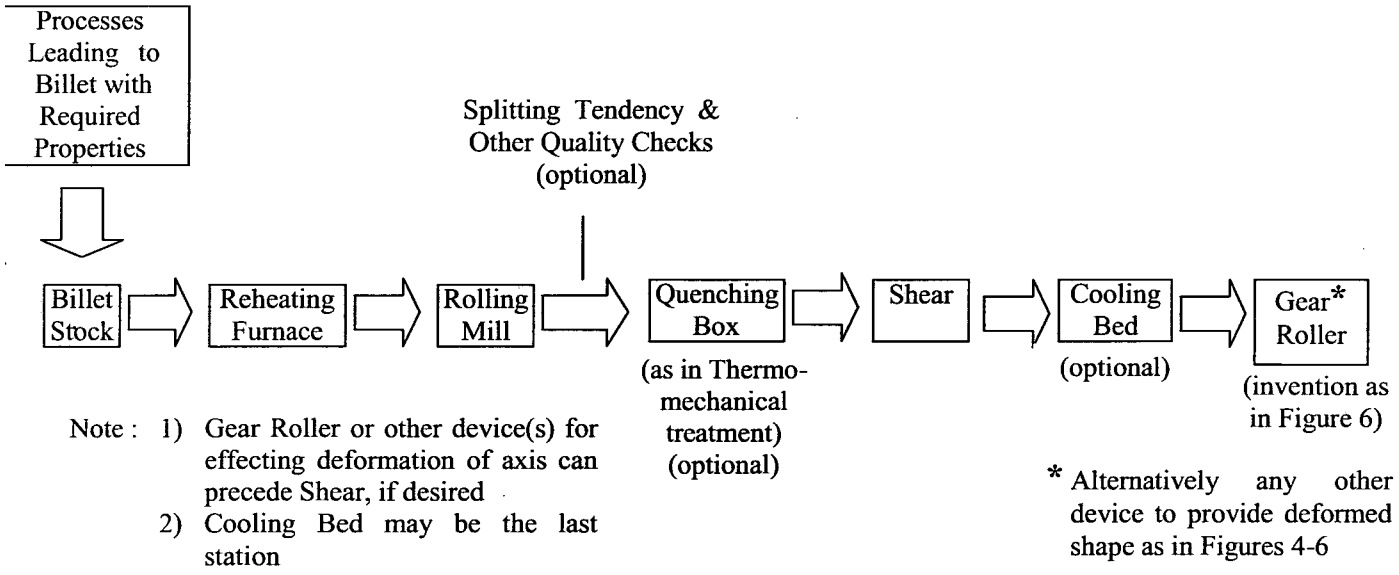

FIGURE 9

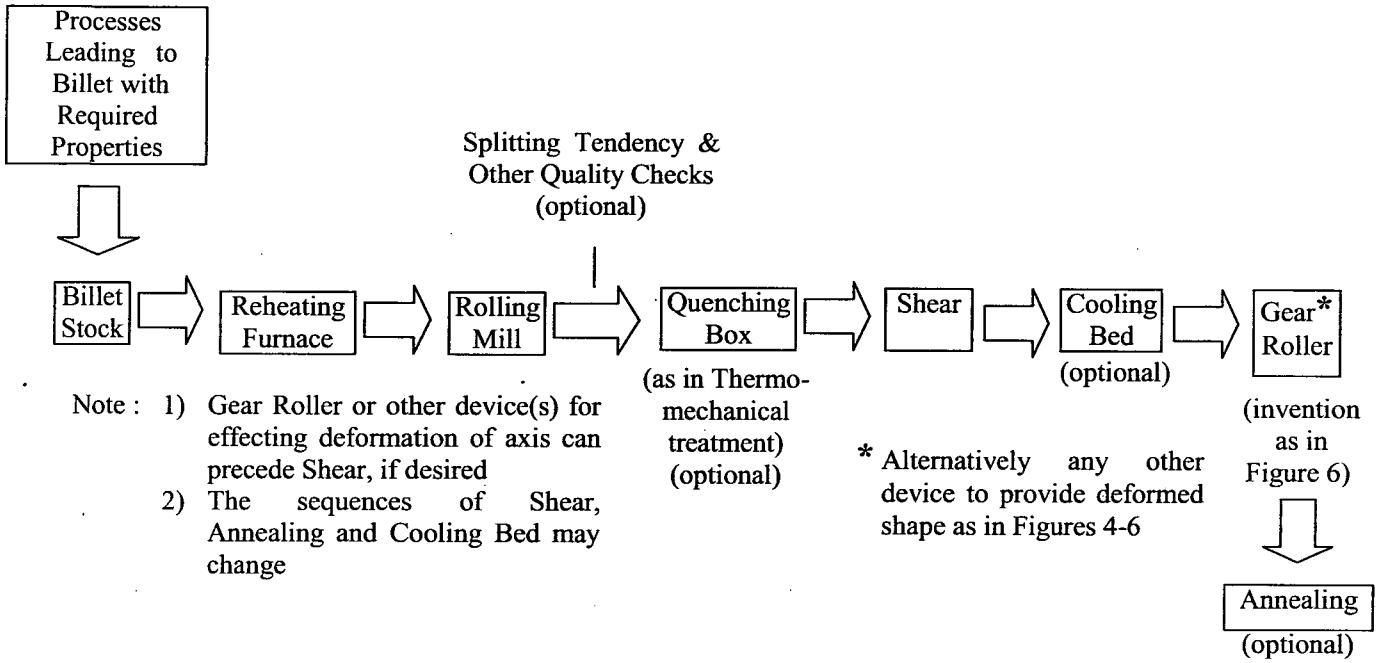
Processes Leading to Billet with Required Properties
Billet Stock
Reheating Furnace
Rolling Mill
Splitting Tendency & Other Quality Checks (optional)
Quenching Box
(as in Thermo-mechanical treatment) (optional)
Shear
Cooling Bed
(optional)
Gear* Roller
(invention as in Figure 6)
Annealing
(optional)
Note : 1) Gear Roller or other device(s) for effecting deformation of axis can precede Shear, if desired
2) The sequences of Shear, Annealing and Cooling Bed may change
* Alternatively any other device to provide deformed shape as in Figures 4-6

FIGURE 10