BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

HIGH STRENGTH DEFORMED BARS

Introduction

Structures reinforced with high strength deformed bars are generally superior in performance and are on the whole more economical than those reinforced with conventional mild steel bars. These bars have yield stress in the range of 35,00 (50 ksi) to 56,00 (80 ksi) kg/cm² and have a considerably higher bond resistance than ordinary M.S. bars.

This type of reinforcement is fast replacing plain M.S. bars in U.S.A. and Europe. The American Society of Testing Materials has issued a specification A-305 entitled "Minimum requirements for the deformation of deformed steel bars for concrete reinforcement". Similar codes of practice have been published by several European countries and the U.K. The object of this digest is to familiarise engineers with this development.

Definition and the need

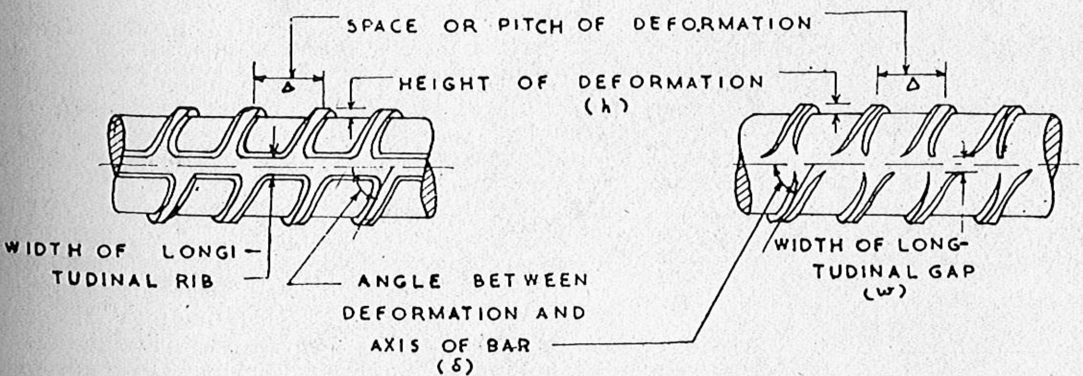
A deformed bar as defined in ASTM A-305 is "A bar provided with lugs or protrusions, hereinafter called deformations, which inhibit longitudinal movement of the bar relative to concrete surrounding the bar in reinforced concrete". The development of this type of bar is an outcome of constant efforts by engineers to improve the bond between steel and concrete resulting in better structural performance. In the early stages of this development, it was felt that larger the deformation, better would be the bond characteristics. Extensive investigations, however, have established certain optimum and typical surface deformations which have been embodied in the specifications of most of the countries. Two typical deformed bars with their geometrical characteristics are illustrated in fig. (1).

It has been established from economic considerations that, to exploit the better bond stresses developed due to surface deformations, allowable tensile stresses must also be increased. The increase in the permissible tensile stresses without any reduction in the factor of safety is possible only with the use of high strength steel bars.

Manufacturing process

Most bars are manufactured by one of the two processes, hot rolling or cold working.

(i) **Hot rolling alone** :—The bars in this process are rolled from naturally hard steel and their high strength is due to comparatively high carbon content



δ .... NOT TO EXCEED 45°

Δ .... NOT TO EXCEED 7/10 OF NOMINAL DIAMETER.

w .... NOT TO EXCEED 12½% OF NOMINAL PERIMETER

h ...., ... TO RANGE BETWEEN 4 TO 5 % OF NOMINAL DIAMETER

FIG. 1

and certain alloying elements. Swedish 'KAM' and British 'GK' steels are typical examples of this type.

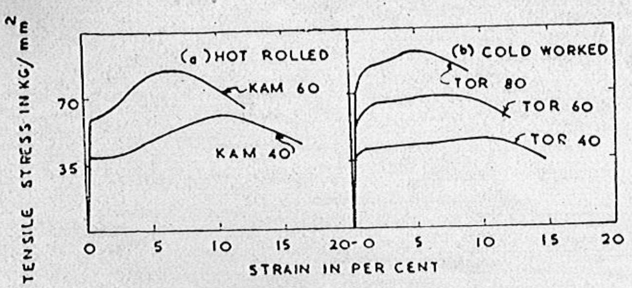
(ii) **Cold working combined with aging after rolling** :—The cold working raises the yield point as well as the ultimate strength of steel. Increase in ultimate strength is also influenced by the phenomenon of 'aging', which is a slow change in the properties of steel during the first few months after cold working. Austrian—German 'TOR' steels are typical examples of this type.

The surface deformations consisting of reversed double helical transverse ribs with or without two continuous opposite longitudinal ribs parallel to the axis of the bars are, however, produced during the rolling operation itself in both the processes.

Properties

The particulars of some of the bars currently in use on the Continent and the United States are given in Table 1.

The typical stress strain curves for hot rolled and cold worked bars are given in fig 2. In the absence of a definite yield point in most of these steels, stress



FIG·2-STRESS STRAIN RELATIONSHIP OF BARS

corresponding to 0.2% strain is adopted as proof stress and is referred to as yield stress as well. The difference in the stress-strain properties of hot rolled and cold worked bars is insignificant in the proof stress range. Thus the choice of these bars is purely governed by the economic and cost considerations.

Advantages

A deformed bar is capable of developing a much higher bond stress than an equivalent plain bar. On an average, it is twice that for a plain bar and this has been recognised by various codes of practice. The bond characteristics are improved by the mechanical locking action of the protrusions in addition to the usual surface bond. These increased permissible bond stresses permit higher allowable tensile stresses in steel, resulting in considerable economy in steel consumption. The reduction in steel area accompanied by higher permissible steel stress, eliminates steel congestion thereby facilitating concreting operations. This also permits width reduction of certain members thus reducing dead loads. Column sizes in multistoreyed structures can also be reduced with the use of these reinforcements. Reduced lap lengths are enough for these bars and the method of splicing them is in no way critical. Also, from the point of view of construction, the deformed bars are superior in that the fabrication of reinforcement is rendered easier. Since the end hooks are not necessary, they are easy to tie and place in position.

Use of standard high strength deformed bar is a highly effective crack control measure. Crack-width in members reinforced with such deformed bar is less than one half of those with plain bars. A structure reinforced with deformed bars under overloads develops a large number of well-distributed fine cracks in contrast to a small number of deep cracks formed, when plain bars are used. It has also been observed that a member reinforced with deformed bars stands reloading cycles better than a similarly reinforced member with plain bars even when the bottom concrete has cracked.

Compared to plain reinforcement bars, the resistance to corrosion is superior in the case of cold worked high strength steel deformed bars.

TABLE 1

Name of bar		Country of origin	Manufacturing process	Yield stress kg/mm²	Working stress kg/mm²
KAM	40	... Sweeden	Hot rolling	40	20
KAM	60	... ,,	,, ,,	60	30
KAM	90	... ,,	,, ,,	90	50
NERSID		... French	,, ,,	40	26
GK	60	... U.K.	,, ,,	42	21
TOR	40	... Austrian—German	Cold Working	40	20
TOR	60	... ,,	,, ,,	60	30
TENTOR		... Danish	,, ,,	50	23

Typical chemical composition of a hot rolled bar KAM 40 is 0.45%C. 0.50% Mn and 0.40% si.

Disadvantages

On account of its lower ductility, stringent cold bend tests have to be stipulated in the codes to safeguard against brittle fractures.

It has been observed that at low temperatures some of the bars tend to become brittle and any rough-handling can cause fracture.

Most of the high strength steel bars cannot be welded satisfactorily in the field, although under shop conditions this is not impossible. However, the chemical composition of steel should be a basis for selection of proper welding procedures. For cold worked steel, careless welding may lead to strength loss by annealing, although some of the correct welding procedures developed by the continental countries give perfect weld in praetice.

Criteria for Design

An engineer designing a structure with high strength deformed bars has to keep certain special considerations in mind. It is quite likely that the high permissible steel stresses may not be exploited to the maximum extent because the requirement of limitation of crackwidth may be wholly decisive in some cases while the requirement of limitation of deflection may be decisive in some others. Accordingly, we have several 'ceilings' involving several parameters which are applicable at the same time. Which of these 'cellings' will be the deciding factor is a question that depends on circumstances.

The extensive studies of ultimate load design made so far have to a large extent elucidated the factors or parameters which determine the ultimate load in bending of members reinforced with various grades of reinforcing steel and for several types of the concretes differing in strength. The reliability of these methods of design is decisively better in cases where the failure is by the yield of the reinforcement. Thus, the fact that the relation between the ultimate load and the reinforcement is fairly well known, makes it possible to increase the permissible stresses in proportion to the yield point.

The structures must be carefully checked for shear since, it has been reported that, after the appearance of first shear crack is a beam, reinforced with deformed bars without hooks and stirrups, failure occurs suddenly without any warning. Under similar circumstances, in beams reinforced with plain bars and provided with end hooks but not equipped with stirrups, there is ample warning of an impending failure and often times the failure load may be twice as much as the load at the appearance of the first shear crack. Hence, it has been accepted as a safe practice to provide stirrups in ample measure to take up shear stresses in concrete. Should the tensile strength of concrete be suddenly exhausted.

Sharp bends in these steels must be avoided since, the risk of local splitting or local crushing of concrete due to high concentration of stresses are regarded serious.

The design should also be checked with respect to crack width at the design load. The crackwidths and the crack spacing have been shown to be a direct function of the stress level in the steel and the distribution of steel in the tensile zone. The crack formation is, however, shown to be independent of the strength of the concrete. Satisfactory crack control to any desired extent at steel stresses as high as 37 kg/mm² is possible, choosing optimum diameter and proper disposition of the bars.

Deflections are often higher with the use of high strength deformed steel reinforcement since the area of steel is substantially reduced. Checks on limitation of deflection are essential from the point of view of safety and aesthetics.

Economies

The savings in the quantity of steel are obvious, since for a given tensile force a lesser area of high strength steel would be sufficient. Considering the tensile force to be carried, the areas of steels are directly proportional to the permissible stresses. However, as mentioned earlier, full tensile strength of these steels can rarely be exploited because of several ceilings. Additional economy results from the elimination of end hooks,

Though extensive cost figures are not available, it may be seen from the relative cost data presented in fig. 3 that the economies in the total quantity of steel out-weigh the increased cost of manufacture. The saving would depend on local circumstances. Fig. 3 also demonstrates that tonnage cost per unit yield point decreases as yield point increases.

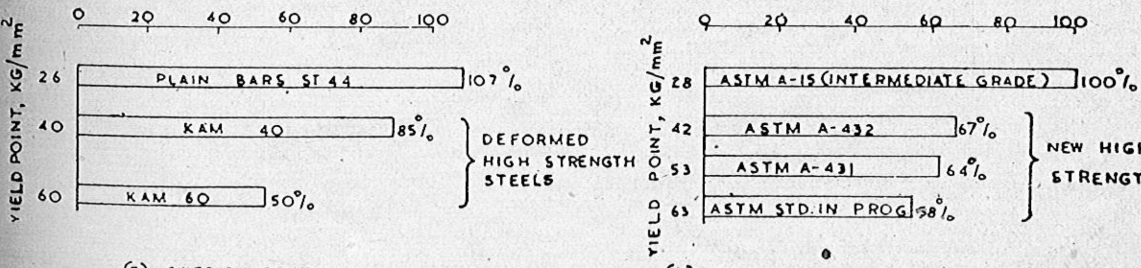


FIG 3-RELATIVE COST OF HIGH STRENGTH REINFORCEMENT

It must however be emphasized here that the overall economy is dependant on several factors apart from the cost of steel. With the use of deformed bars, it has been observed that as per the elastic design procedures, the increased allowable stresses in steel reduce the compression zone, in other words the neutral axis moves upwards. Consequently for a balanced section, to match the total tensile force, it is necessary either to permit higher stresses in concrete or 'make up' the area of the compression zone with increased width, if no change in depth is desired. Permitting of higher stresses in concrete brings in its wake the use of richer concrete and thus from either consideration, the cost of concrete increases. This to certain extent affects the overall economy.

To sum up, with the use of deformed steel bars, there is a decisive saving in the quantity of steel, coupled with ease of construction while the overall economies are dependent on several factors and should be independently assessed for each type of structure.

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