High-Strength Deformed Bars for Concrete Reinforcement

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There seems to be a wide difference of opinion, amongst Engineers in Ceylon, about the advantage which high strength deformed bars possess over mild steel bars for use as concrete reinforcement. Faced with the question of whether or not a Ceylon Standard for high-strength deformed bars needed early drafting the Bureau of Ceylon Standards sought the advice of a number of our Engineers. Some of the opinions expressed would have given a layman the impression that deformed bars are a decorative type of reinforcement, uneconomical and specified only by ignorant foreign consultants! It is therefore imperative that the properties and uses of deformed bars be investigated carefully by all our Engineers and the question of saving steel by replacing plain round mild steel bars by high-strength bars, wherever economical, be given early consideration. The author hopes that the observations made in this paper will arouse a greater interest in the use and local production of high strength bars, thus effecting a substantial saving in steel and, therefore, foreign exchange.

Introduction

There is an urgent national necessity to conserve every possible amount of building material by putting these to their most efficient use, consistent with accepted safety standards. This is particularly so when the material has to be imported or when the available local supplies are limited. This paper gives the results of an investigation into the origin and the use of deformed steel bars and also the economy which could be achieved thereby, with particular reference to reinforced concrete work in Ceylon.

High-strength bars can be produced either by hot-rolling of suitable high-carbon steel billets or by cold-working of mild steel bars. Cold-twisted mild steel bars appear to have been used in industrialised countries more or less as a first step towards the general use of deformed bars. Since the Ceylon Steel Corporation is already engaged in the rolling of mild steel bars, it would be possible to put into immediate use the knowledge of cold-working processes which other countries have patiently gathered through
many years of expensive research and experimentation. The hot-rolling process would involve a larger initial capital outlay and also continuing expenditure of additional foreign exchange for importing high-carbon steel billets.

The work done in India on a method of producing twin-twisted steel bars is carefully considered. Based on the measurements of torque during experimental production of twin-twisted bars in the University of Ceylon laboratories, a simple inexpensive, hand-operated twisting machine is being developed. This can easily be used even on building sites by unskilled workmen. The saving in steel due to the use of such bars on some Indian projects have been reported to be around 30%. The saving in overall cost would depend on various factors, but is expected to be greater than 5%.

The calculations reported herein have been carried out according to the B.S. Code of Practice for Reinforced Concrete, No. 114, in the absence of an appropriate Ceylon Standard Code of Practice. The quality of mild steel has been taken as that presently produced by the Ceylon Steel Corporation for which specifications have been drafted by the Bureau of Ceylon Standards.

Historical Development

When concrete, reinforced with mild steel bars, was first used in structural construction work, knowledge of the material was very limited, laboratory and field experience of the behaviour of reinforced concrete members was inadequate and rational design procedures were unknown. Moreover, the principles governing the proportioning of concrete mixes were not understood and, therefore, the quality of concrete was not consistent. In spite of such shortcomings, bond failures were not usually encountered. Nevertheless, there was a widespread desire to provide good mechanical bond. Designers adopted various types of end anchorages and the standard hooked-ended tensile bar came into general use. This is in common use even today; Reinforcing steel manufacturers began to provide special projections on the surfaces of the bars, and a large variety of patented products were available in many countries. Despite the apparently more effective bond to be expected, no increase in permissible stress was used by designers. This was fortunate as, subsequently, some of these bars were found to be even less effective than plain bars. This was so because a bar with any arbitrary pattern of projections was claimed to be superior to plain round bars. These experiences together with the higher cost of "deformed" bars made designers in some countries, including Britain, stop using such reinforcement. All our engineers, at that time, were British trained and engineering practice in Ceylon would necessarily have reflected the trend in Britain. This, perhaps, accounts for the fact that deformed bars have not been widely used in this
country until quite recently, and even then mainly in projects designed abroad. However, the bridges section of the Public Works Department has been using deformed bars for the past ten years.

The first deformed bar is reported to have been produced in the U.S.A. as early as 1884 and this consisted of a square bar, twisted cold, so that the edges made a very small angle with the axis of the bar. Since then, extensive research has been carried out by individuals, by manufacturers trying to prove their claims of superior quality and also by organisations backed by the American Iron and Steel Institute and the U.S. National Bureau of Standards. Perhaps, the most noteworthy of these early contributions on this subject were given by Menzel (1939, 1941) and Clark (1946). In June 1947, official recognition of deformed bars was given for the first time, when the American Society for testing Materials published their tentative specifications No. A 305, "Minimum requirements for the deformation of Steel Bars". Deformed bars came into widespread use in many countries with the acceptance by the American concrete Institute Building Code No. 318, March 1951 of the use of higher bond stresses for deformed bars complying with the A.S.T.M. Specification. At approximately this same time economical ways of rolling deformed bars and maintaining the rolls were developed by the industry so helping to bring down the cost of this type of reinforcement.

It is now generally accepted that bars deformed according to standard specifications are approximately twice as efficient in bond as plain bars, although the actual value varies in individual cases. However, there is no practical advantage in using mild steel deformed bars, since the high bond resistance cannot be made use of unless the bars can be stressed to higher values than those possible with mild steel. Therefore, in order to obtain effective use of the possible increase in bond resistance, the steel must possess high-yield-stress characteristics as well. The ultimate strength is of little importance because steel cannot be stressed to a strain exceeding about 0.2% as the concrete would then have attained its ultimate strain of about 0.35%.

MANUFACTURE AND PROPERTIES OF HIGH-YIELD-STRESS BARS

Hot-rolling and Cold-working Processes

High-yield-stress deformed bars can be produced by the hot-rolling of suitable high-carbon steel billets or by the cold-working of mild steel bars.

In the hot-rolling process, the longitudinal and transverse projections, which provide the improved bond, are produced during rolling at high temperatures. The higher strength is obtai-
ned by adjusting the chemical composition of the steel. The American ribbed bars, the British GK60, the French NERSID and the Swedish KAM are examples of hot-rolled bars.

In the cold-working process, ordinary mild steel bars are subjected to overstrain, usually in torsion combined with tension. Overstraining in this manner produces a bar with properties desirable in reinforcing steel. These phenomena have been explained by metallurgists. The crystal structure of the steel is re-oriented during the overstraining process in such a manner that subsequent deformation in tension or compression is made more difficult. In the case of bars which are to be used for single-twisting, the projections which provide improved bond, are rolled-in during the manufacture of the mild steel bars. A twin-twisting process of cold-working known as the ISTEG process, was introduced in the 1930s and has been widely used in many countries. In this, two plain round bars, initially straight and parallel, are twisted together to form a double helix. During twisting, the ends of the bars are restrained against free longitudinal movement, thereby subjecting the bars to tensional forces. Experimental work carried out in India has shown that similar properties and shape could be obtained even when free longitudinal movement is permitted during twisting. These findings have enabled the cost of twin-twisting equipment to be greatly reduced as the heavy anchoring devices used to prevent longitudinal movement in the original ISTEG process are no longer required. The Danish TENTOR, Austrian TOR and the French CARON are examples of cold-worked bars.

Some of the types of hot-rolled and cold-worked bars mentioned above are shown in Fig. 1.

![Fig. 1. Sketches of high-strength deformed bars.](image-url)
Yield-stress, Ultimate-stress and Modulus of Elasticity

Hot-rolled steels have a definite yield point and the ratio of the yield-stress to the ultimate-stress is about 2/3. In the case of cold-worked steels, there is no well-defined yield point and, therefore, an equivalent yield stress or a proof-stress has to be introduced. The equivalent yield stress is taken as the stress at which the extension is 1/3% of the original gauge length. The proof stress is the stress at which the stress strain curve departs by a certain percentage (usually 2%) of the gauge length from the linear portion. The number of twists is usually specified so as to ensure that the equivalent yield stress is not too close to the ultimate-stress thereby reducing the margin between initial failure and collapse. A value of the ratio of yield stress to ultimate stress between 0.8 and 0.9 is usually acceptable.

The modulus of elasticity of a steel is practically unaffected by a change in chemical composition of the extent required to give the high strength in hot-rolling processes. It is unchanged by cold-working too, but the modulus of twin-twisted bars is about 4 of that of the original material because of the "rope-tightening" effect.

Permissible stresses

As in the case of mild steel, the permissible stresses would depend on the purpose for which the bars are used. These stresses are generally related to the yield-stress or proof-stress, the permissible-stress usually being taken as half the yield-stress. However, overall upper limits are specified in order to safeguard against excessive cracking of concrete or elastic buckling of reinforcement. In tensile reinforcement, a maximum stress of 30,000 lbf/in² is usually specified; in shear reinforcement, the limiting value is 20,000 lbf/in² whilst in compressive reinforcement, it is 23,000 lbf/in². In the case of twintwisted bars, where each bar is curved, the tendency to buckle under compression is great and such bars, therefore, are not recommended for use as compression steel.

Bond stress values up to 50% greater than the usual values have been adopted, but the British Standard Code of Practice recommends a rather low percentage increase of 25.

In structures used for the storage of liquid, where cracking must be avoided, the maximum tensile stress is limited to 12,000 lbf/in² in accordance with current design practice. A slight increase in this value, up to a maximum of 15,000 lbf/in², has been proposed in view of the fact that the bond between the concrete and steel is very good. It has been claimed that this would tend to reduce the tendency to crack. The improved bond, however, would reduce only the tendency for large cracks to form under
high loads and the effect on initial cracking is not appreciable. Thus, there is little advantage in using high-strength steel for reinforcing such structures. With the ready availability of relatively cheap epoxy resins, which are resistant to chemical attack and are non-toxic, there is likely to be tendency to use such materials in the form of a protective coating on the liquid retaining face of the structure. There is already a trend in this direction in some countries. In such cases, the use of 15,000 lbf/in² as the permissible stress in high-bond bars may be justified.

**Ductility**

The ductility of high-yield-stress bars will depend to a great extent on the method of production. It is indeed possible to cold-work a given mild steel bar to obtain a specified yield stress, ultimate stress or elongation (within limits, of course), by controlling the pitch of twists. The minimum specified elongation for bars over 1 in is 16%, for bars between 3/8" and 1" it is 14% and for the bars below 3/8" it is 12%. The values for corresponding sizes of hot rolled high-strength bars are 22, 18 and 14 whilst for mild steel they are 24, 20 and 16 per cent.

**Bond Characteristics**

The increase in bond resistance in bars having specified deformations is considerable. There is however an essential difference in the bond failure mechanism between a normal round bar and a deformed bar. With the round bar, the bond stress along the bar progressively increases to a maximum value and then decreases. Final failure is due to crushing of the concrete in contact with the bar and subsequent separation and the withdrawal of the bar from the concrete. In the case of deformed bars, mechanical wedging takes place between the concrete and the projections on the steel. The bond stress increases to high values and final failure is generally due to bursting, in tension, of the concrete cover on the steel. On account of this phenomenon, an increased concrete cover may be desirable, but, for the permissible increase in bond stress values, an increased cover is not really necessary.

The bond characteristics of deformed bars lead to the formation of a large number, but finer, cracks than in the case of plain bars. Excessive cracking due to localization is thus prevented resulting in an increased protection against corrosion.

**Fire Resistance**

Since heat would tend to destroy the effects of cold-working, the fire-resistance and the durability under tropical conditions have sometimes been questioned. Experimental observations have cleared up these doubts. The effects of cold-working are stable for indefinite periods at air temperatures. Prolonged heating up to about 1100°F may drop the ultimate strength by
about 10% and the yield stress by about 15%. Heating to about 1600°F for an hour removes completely the effects of cold-working. These observations must be considered together with the effects of heat on mild steel. At about 900°F the modulus of elasticity of mild steel drops to about 1/3 the original value, the yield point is no longer well-defined and the value of the ultimate strength is reduced by about 50%. Thus collapse is more likely to occur in structures reinforced with mild steel rather than in those with cold-worked bars. However, the proportionate loss of strength is higher in the case of structures reinforced with the cold-worked bars and therefore it may be advisable to avoid the use of such bars whenever fire-resistance is an important design consideration.

Impact Resistance

The use of high-yield-stress reinforcement has sometimes been criticized on the grounds that concrete reinforced with these are less resistant to shock. The only reason for this criticism seems to be that the amount of experimental results on the impact strength of reinforced concrete is limited. Available test results show that there is no noticeable difference in the impact resistance whatever the type of reinforcement. The failure of a reinforced concrete member under impact loads occurs when a single blow is severe enough to elongate the steel up to the point of fracture. Under normal impacts the strain is very unlikely to exceed the elastic stage. In any case, deformed bars have been used in bridge construction work for a long time without any signs of distress and there should now be no fear about their capacity to resist normal impact loads, provided that the usual considerations are given to impact factors during the design stage.

Weldability

Bars produced by hot-rolling processes can be welded without altering the properties of the steel. Since the action of intense heat tends to destroy the effects of cold-working, bars produced by cold-working processes should not be welded. Thus, hot-rolled bars have a wider application than cold-worked bars.

Economical Aspects

High-strength bars are necessarily more expensive than mild steel round bars. The higher permissible stress, however, results in a considerable saving in steel. A case study of a typical six-storey office building, carried out recently at the Structural Engineering Research Centre, Roorkee, India has shown that the saving in steel can be as much as 42%. Other investigations have shown savings over 30% (e.g., Ramaswamy). In a country which imports steel, the lower freight charges on the smaller amount of high-strength bars would offset a part of the increased purchase price.
The overall economy in a particular project can be estimated only by a comparison of actual alternative designs, as the total saving depends on many factors, including the constructional techniques and design principles adopted. Such investigations are rather tedious and time-consuming. According to some investigations carried out in India, overall savings of between 6% and 12% have been obtained using twin-twisted steel. Some of the factors which contribute to the overall economy are briefly considered here.

**Tensile Reinforcement in Beams and Slabs**

An idea of the saving in materials can be obtained by carrying out alternative designs using materials of different permissible stresses. Table 1 shows alternative designs for "economical" sections for a singly reinforced beam carrying a superimposed load of 500 lbf/ft over a span of 20 ft. The modular ratio method as well as the load-factor method have been used so as to investigate the relative merits of these two design principles. The following trends may be observed:

1. The use of high-strength bars results in a considerable saving in steel when compared with the quantity of mild steel required for reinforcing an equivalent beam. The increase in the amounts of concrete (and shuttering) is not appreciable. The use of better quality concrete brings about a saving in concrete too.

2. The modular-ratio method gives a cheaper design than the load factor method for "economical" sections. The saving in concrete and shuttering effected by the latter method is not sufficient to offset the increased cost of steel. However, in tall buildings, the reduced weight of concrete might result in smaller columns and foundations and, thereby, result in an overall economy through the use of the load-factor method.

3. If the section dimensions are determined by the modular-ratio method, the area of steel calculated by the modular-ratio method as well as the load-factor method are very nearly the same.

**Shear Reinforcement in Beams**

The spacing of inclined bars, calculated according to the commonly used "lattice-girder" analogy is 1.41 times that of the depth of the girder for a 45° inclination of the bar, when the steel stresses in the horizontal portion and the bent-up portion are the same. As discussed in the section on permissible stresses, the maximum stress in the bent-up portion is limited to 20,000 lbs/in². In the horizontal portion however, the full permissible tensile stress (27,000 lbf/in² in the high-strength steel under consideration) may be allowed. For such a case, the spacing of bars is 1.91 times the depth of the lattice girder, giving a considerable saving in steel.
<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Concrete stress (lbf/in²)</th>
<th>Modular ratio method</th>
<th>Load factor method</th>
<th>Steel area (in²)</th>
<th>Percentage saving</th>
<th>M. R. method</th>
<th>L. F. method using M. R. section</th>
<th>Concrete</th>
<th>Steel</th>
<th>Concrete</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel:</td>
<td>750</td>
<td>12 x 19</td>
<td>12 x 15</td>
<td>1.59</td>
<td>2.20</td>
<td>1.64</td>
<td>-25</td>
<td>+19</td>
<td>+0</td>
<td>-13</td>
<td></td>
</tr>
<tr>
<td>min. yield stress = 37,000 lbf/in²</td>
<td>1000</td>
<td>12 x 15</td>
<td>12 x 13</td>
<td>1.95</td>
<td>2.49</td>
<td>2.03</td>
<td>-</td>
<td>+14</td>
<td>-18</td>
<td>+21</td>
<td>-42</td>
</tr>
<tr>
<td>High-strength steel:</td>
<td>1250</td>
<td>12 x 13</td>
<td>12 x 12</td>
<td>2.30</td>
<td>2.76</td>
<td>2.37</td>
<td>+14</td>
<td>-18</td>
<td>+21</td>
<td>-42</td>
<td></td>
</tr>
<tr>
<td>min. yield stress</td>
<td>750</td>
<td>12 x 21</td>
<td>12 x 16</td>
<td>0.96</td>
<td>1.52</td>
<td>0.94</td>
<td>-41</td>
<td>+51</td>
<td>-7</td>
<td>+22</td>
<td></td>
</tr>
<tr>
<td>&lt;54,000 lbf/in²</td>
<td>1000</td>
<td>12 x 17</td>
<td>12 x 14</td>
<td>1.19</td>
<td>1.73</td>
<td>1.23</td>
<td>-14</td>
<td>+39</td>
<td>+7</td>
<td>+11</td>
<td></td>
</tr>
<tr>
<td>Twin-twisted mild steel:</td>
<td>1250</td>
<td>12 x 14</td>
<td>12 x 12</td>
<td>1.41</td>
<td>1.89</td>
<td>1.47</td>
<td>+6</td>
<td>+28</td>
<td>+20</td>
<td>+3</td>
<td></td>
</tr>
<tr>
<td>Equivalent yield stress</td>
<td>750</td>
<td>12 x 16</td>
<td>12 x 16</td>
<td>0.89</td>
<td>1.52</td>
<td>0.97</td>
<td>-55</td>
<td>+55</td>
<td>-7</td>
<td>+22</td>
<td></td>
</tr>
<tr>
<td>&lt;54,000 lbf/in²</td>
<td>1000</td>
<td>12 x 18</td>
<td>12 x 14</td>
<td>1.11</td>
<td>1.73</td>
<td>1.13</td>
<td>-20</td>
<td>+43</td>
<td>+7</td>
<td>-11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1250</td>
<td>12 x 15</td>
<td>12 x 12</td>
<td>1.32</td>
<td>1.89</td>
<td>1.33</td>
<td>-0</td>
<td>+33</td>
<td>+20</td>
<td>+3</td>
<td></td>
</tr>
</tbody>
</table>
When stirrups are used as shear reinforcement, any saving in steel effected would not be sufficient to offset the greater cost of the high-strength bars. Mild steel, therefore, is to be preferred for stirrups.

**Columns**

On account of the limit of 23,000 lbf/in² imposed on the maximum stress in compressive steel, the use of high strength bars in axially loaded columns is not usually economical. Calculations carried out on a large number of axially loaded square columns ranging from 8" × 8" to 36" × 36" reinforced with the minimum and maximum percentages of steel (0.8% and 8% respectively of the gross cross-sectional area of the column) showed that the increase in the load varied between 11% and 17% when high-strength steel was used, with a concrete permissible stress of 1000 lbf/in² (i.e. 760 lbf/in² in direct compression). With the higher strength concrete, the values were much lower.

In the case of columns subjected to large bending moments the remarks relating to beams would apply. When the bending moments are small, the use of high strength bars results in very little economy.

**Lap Lengths and End Anchorages**

In designs using mild steel bars, a large quantity of steel is used in overlaps, bond lengths and anchorages. The minimum length required to develop, by bond, the force in a round bar is \( P_s D / 4P_b \) where \( P_s \) is the permissible stress in the steel, \( P_b \) is the allowable bond stress and \( D \) is the diameter of the bar. When \( P_s \) is compressive, \( P_b \) may be increased by 25%. In the case of deformed bars of non-circular cross-section, \( D \) is taken as the diameter of the circle having the same cross-sectional area as the bar. According to B.S. Code of Practice No. 114, the value of \( P_b \) usually specified for plain bars may be increased by 25%, if the standard pull-out test shows that the bond value is at least 25% superior to that of a plain round bar. The actual bond resistance of present-day ribbed and twisted bars warrants a higher percentage increase, but an increase of more than around 50% will bring about attendant problems of providing extra cover to prevent the tendency of the concrete surrounding the steel to burst.

**TABLE 2**

<table>
<thead>
<tr>
<th>Type of Bar</th>
<th>Bond Stress (lbf/in²)</th>
<th>Bond lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tensile Stress (lbf/in²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18,500</td>
</tr>
<tr>
<td>Mild steel</td>
<td>120</td>
<td>38.5D</td>
</tr>
<tr>
<td>Deformed</td>
<td>150</td>
<td>31D</td>
</tr>
</tbody>
</table>
## Table 3
Economy in bond lengths

<table>
<thead>
<tr>
<th>Type of Bar</th>
<th>Weight of bond length of deformed bar</th>
<th>Weight of bond length of mild steel bar</th>
<th>Tensile Stress (lbf/in²)</th>
<th>Compressive Stress (lbf/in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ratio of</td>
<td></td>
<td>18,000</td>
<td>23,000</td>
</tr>
<tr>
<td></td>
<td>Weight of bond length of mild steel bar</td>
<td></td>
<td>18,500</td>
<td>27,000</td>
</tr>
<tr>
<td></td>
<td>Tensile Stress (lbf/in²)</td>
<td>Compressive Stress (lbf/in²)</td>
<td>30,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Square Twisted</td>
<td>0.80</td>
<td>0.79</td>
<td>0.79</td>
<td>0.72</td>
</tr>
<tr>
<td>Twin-twisted</td>
<td>0.64</td>
<td>0.63</td>
<td>0.63</td>
<td>—</td>
</tr>
</tbody>
</table>

Deformed bars are not usually provided with end anchorages unless the required minimum lengths cannot be provided in a straight length. This results in a slight saving in bar-bending costs. A comparison of the bond lengths for mild steel round bars and deformed bars in concrete having a permissible stress in bending of 1000 lbf/in² is given in Table 2. The ratios of the weights of the bond lengths of two types of cold-worked bars (which could be conveniently produced in Ceylon) to the weight of the bond length of equivalent mild steel bars are given in Table 3. In the case of the mild steel in tension, a standard hooked end, which gives a saving in bond length of about 4D has been considered. These values give an idea of the saving in steel brought about by the smaller size of high-strength bar required to resist a given force.

### Towards Local Production of High-strength Bars

In order to economise in the use of reinforcing steel, mild steel bars should be replaced, wherever economical, by high-strength bars. It is reported that in certain parts of the U.S.A., plain round bars were at one time more expensive than high-strength bars so that engineers were compelled to incorporate the latter type of reinforcement in their designs. In order to encourage our designers to specify high-strength bars, it is necessary to make these freely available at a price which would be economical from the point of view of the user.

The cost of production of high-strength bars will depend on many factors. In the context of the prevailing economic conditions in Ceylon, it is very necessary to keep the foreign exchange component of the cost to a minimum. The sole manufacturer of reinforcing bars in the country, the Ceylon Steel Corporation, at present roll mild steel round bars from imported billets. The rolls are turned out locally and there should be no difficulty in turning out bars similar in shape to the Tor and Caron bars (see Fig. 1). Cold-working, therefore, seems to have an advantage
over the hot-rolling of high carbon steel billets. A periodical check on the relative total costs of production, nevertheless, would be desirable. It is interesting to note that the Indian Steel Rolling Mills Limited of Madras have recently entered into technical collaboration with the Tor-Isteg Steel Corporation for the production of cold-worked high-strength bars, similar in appearance to the Tentor bar shown in Fig. 1, under the trade name Tor-steel. The marketing price, reported to be only slightly higher than that of mild steel and being in the region of Rs. 120/- per ton, gives the user an appreciable saving. Whilst it is worthwhile investigating the economics of technical collaboration with a well-established manufacturer, the possibility of embarking on independent production should be given very careful consideration.

The specifications, usually referred to in American, British and Indian publications for the provision of the high-bond projections in hot-rolled bars, are those given in the American Society for Testing Materials Standard A 305-50T. Canadian and Czechoslovakian bars which have been tested at the University laboratories generally conform to these requirements which have been drafted on the basis of a large number of experimental results. Whatever pattern of projections is provided, its suitability should be judged by the consistency with which high bond resistance is obtained. For this purpose, a standardised pull-out test, as well as a beam bending test and an embedded rod test have been recommended.

Some types of cold-worked bars can be produced locally with very little initial capital outlay. Twin-twisting of mild steel round bars, which are presently being rolled by the Ceylon Steel Corporation, seems to be the simplest cold-working process to adopt. In fact many countries used twin-twisting methods in the early stages of producing high-strength bars. The cost of equipment was high at first, but the work done in India at the Central Building Research Institute since 1953 has helped to eliminate the most expensive aspects of the twisting machines. These investigations have shown that twin-twisting with or without longitudinal restraints at the end gives practically the same results. In the latter case, however, the cost of equipment is very little. The effects of twisting mild steel bars are shown in Fig. 2. The results obtained by Reynolds (1944) on squire twisted bars and by Billing (1954) on twin-twisted bars, are plotted in Fig. 3, to show the effect of the pitch of twists on the stress values. If the pitch is low, the difference between the ultimate stress and yield stress is too small to give sufficient warning against failure. If the pitch is high, the properties change very little from those of mild steel. Thus, a range of pitch has to be specified. The twisting processes provide a “built-in” test for the quality of individual bars as unsatisfactory ones would fail during twisting.
The first twin-twisting machine used in India was built from the remains of an old lathe. An electrically operated machine, subsequently designed, is now estimated to cost around Rs. 7000 (Singh, 1967). Once the principle is understood, it is possible to rig up a twisting machine in any workshop.

The University laboratories are reasonably well-equipped to carry out torsion tests, tension tests and the bond tests mentioned earlier. Torque measurements were taken during the twin-twisting of a series of bars up to \( \frac{1}{4} \) in diameter and the maximum value recorded was around 2200 lbf/in. Such a torque can be obtained on a manually-operated machine. A small table machine, devised from broken pieces of torsion testing specimens used in undergraduate experiments, was put together in one morning. Only small diameter bars (up to about 3/16 in) can be twisted by this machine, but it has proved that the rigging up of an inexpensive machine, even on a construction site, is quite possible. Up to now concrete frames for such a machine have been cast but a flywheel arrangement, which could be cast in concrete, too, may become necessary. A warning device, such as a bell, giving an indication of a predetermined number of twists could be incorporated and this would make it possible for unskilled labour to operate the machine. The cost of production would depend on the diameter of the bars; for 12 mm diameter bars, a rough estimate is in the region of Rs. 60 per ton. This seems to be an economical proposition. If an electric motor is used to provide the twisting torque, the cost of production could be reduced.

The Steel Corporation might be in a position to rig up equipment to produce these, as well as other types of single twisted steel bars, with only a marginal increase in price. A portion of this increase, perhaps, could be absorbed by the Corporation, at first, so as to encourage the use of such reinforcement. A close co-operation between the Corporation and the University might be helpful in developing cold working techniques.

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![Stress-strain relationships for plain and twisted mild steel.](image)
A separate Code of Practice for the use of high-strength reinforcing bars would go far to bring about economies in steel by putting the material to its fullest use.

Conclusions

The use of high-strength bars will lead to a saving in steel as well as a saving in overall cost, if these are used effectively in the design stage. For economy in steel at the expense of everything else, higher steel stresses should be used with weaker concrete stresses. If high strength concrete is used, shallower sections are obtained with, perhaps, an overall saving in cost due to the reduced amounts of concrete and shuttering and also due to the smaller foundations which may be required to carry the reduced weight.

As a first step towards the general use of high-strength bars, the substitution of twin-twisted bars for mild steel could be adopted wherever possible. These could be produced, using inexpensive equipment, from the mild-steel round bars now being produced by the Ceylon Steel Corporation.

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