The Tempcore process, designed to produce reinforcing bars with high yield strength, good weldability and superior ductility, involves the direct heat treatment of the bar leaving a hot rolling mill. It is based on the tempering of a previously quenched surface layer by the heat supplied from the core of the product. A total of 26 companies can produce Tempcore bars with an anticipated production of approximately 1.5 million tons in 1984.

Tempcore: A new process for the production of high-quality reinforcing bars

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FOR many years, there has been a strong trend in the European market toward high-quality reinforcing bars. The required qualities are high yield strength, good weldability and superior ductility.

When the guaranteed yield strength of rebars is increased, the weight of reinforcing bars used for a particular construction is reduced and, consequently, the cost of the structure is reduced. This evolution is illustrated by the tendency in European standards to prescribe higher yield strengths. The 400 MPa grade (approximately 60 ksi yield strength) is common while there is already a market for the 500 MPa grade and, in some countries, for the 600 MPa grade.

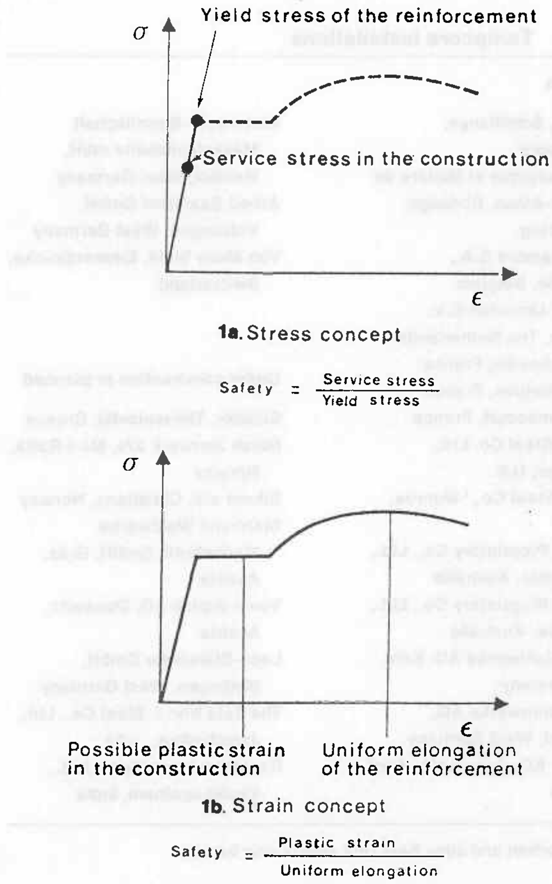
Prefabrication is extensively used as it is advantageous in reducing costs; 3-dimensional reinforcing structures are manufactured in fabrication shops and transported directly on site. This procedure demands assembling techniques which provide the required dimensional accuracy and the maintenance of that accuracy during several handlings until the final positioning at the construction site. In many cases, tied connections have insufficient strength while mechanical splices are not always applicable. Welding then becomes a must. For economic reasons, lap or tack welding of reinforcements needs simple procedures, easy to apply and to control. Thus, preheating must be avoided and, for the shielded metal arc process, the use of titania-coated electrodes must be possible. High carbon steels do not meet these requirements because they are embrittled by the low heat input or are sensitive to hydrogen diffusion. Defined in such a drastic way, weldability of reinforcing bars requires low carbon (C < 0.25% or even <0.22% for the tack welding process) and low carbon equivalent steels (C < 0.45%).

For many decades, the design of a concrete structure was based on a stress concept, ie, on the assumption that the loads which normally appear in service induce only elastic stresses in the reinforcing steel. In such a case, the safety of a structure can be defined in terms of a stress ratio, ie, the ratio between the service stress and yield stress of the reinforcing bars (Fig. 1a).

However, recent research work by the European Committee for Concrete (C.E.B.) has led to the conclusion that a stress-based calculation of the reinforced concrete is not sufficient because, for several structures, local plastic deformations have to be absorbed without failure of the reinforcing bars, eg, when tamping occurs. In these circumstances, the safety of a building is expressed in terms of a strain ratio, eg, the ratio between the local plastic deformation liable to occur and the uniform elongation of the reinforcing bar (Fig. 1b). This design procedure is now adopted in many countries and requires ductile reinforcing steels. Therefore, the requirements for a guaranteed uniform elongation of up to 4% was developed for welded as well as as-received reinforcing bars. Some standards also prescribe that reinforcing bars have to pass a bending and rebending test, even on small-diameter mandrels (down to 3 or 4 times the bar diameter) at −20°C (−4°F).

These requirements led to the definition of a modern reinforcement, ie, a high-strength, weldable, tough and ductile reinforcing bar.

Fig. 1 — Safety concepts used in the design of steel reinforcements.



The Tempcore process

Existing methods for the production of high-strength weldable reinforcing bars can be classified into two distinct categories. The first category consists of bars used in the as-rolled condition after cooling in still air. For these bars, the yield strength can be increased by modifying the chemical composition. The C and Mn contents have to be kept low to avoid a significant decrease in weldability. This problem can be solved by adding small quantities of microalloying elements such as Nb or V. However, this solution is expensive.

The second category consists of bars submitted to a strain hardening after hot rolling, for instance by cold deformation. For such bars, the yield strength can be increased by increasing the amount of strain. This method enables the production of high-strength weldable reinforcing bars but the additional cost of cold deformation is relatively expensive, especially for small diameters. Moreover, it greatly decreases the uniform elongation.

To avoid the drawback of these existing methods, C.R.M. conceived, 10 years ago, the Tempcore process which improves the steel quality and decreases production costs.

After initial laboratory trials at C.R.M., the first industrial Tempcore installation came on stream at the Arbed, Esch-Schifflange plant in 1975. Additional installations in the Benelux countries followed rapidly at Miniere et Metallurgique de Rodange, Cockerill-Sambre and Hoogovens. Soon, new installations were placed in operation, first in Europe and later in other parts of the world. A total of 17 installations are in operation and eight more are planned or will start operation in the near future (Table I). Worldwide expansion of the process is illustrated in Fig. 2, together with predicted production in 1984.

Principle — The Tempcore process essentially consists of a special heat treatment from the heat of rolling, illustrated schematically in Fig. 3.

A bar leaving the last stand of a hot rolling mill passes through a special water cooling system. The cooling efficiency of this system is such that a surface layer of the bar is quenched into martensite, the core remaining austenitic. This quenching treatment is stopped when a determined thickness of martensite has been formed.

When the bar leaves the high rate cooling section, the temperature gradient established in the cross-section causes heat to flow from the center to the surface. This results in a self-tempering of the martensite. The name Tempcore was chosen to illustrate the fact that the martensitic layer is TEMPered by the heat which is left inside the CORE after the interruption of the quenching stage.

Finally, during slow cooling of the bar on the cooling bed, the austenitic core transforms, generally to ferrite and pearlite.

The temperature-time history of a bar is shown in Fig. 3, in relation to the CCT diagram. The three stages of the process are: quenching of the surface layer; self-tempering of the martensite; and transformation of the core. In some cases

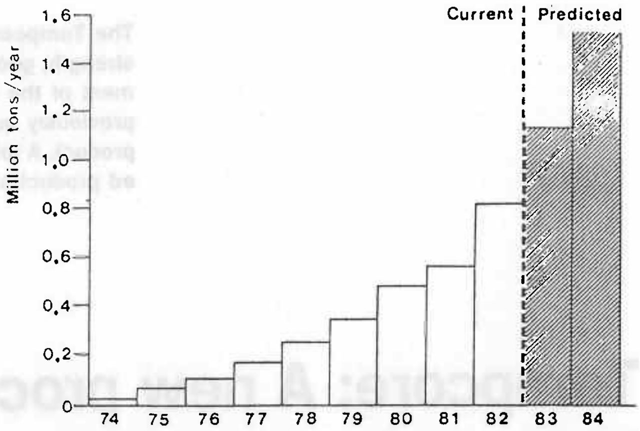


Fig. 2 — Tempcore production.

TABLE I Tempcore installations

In operation

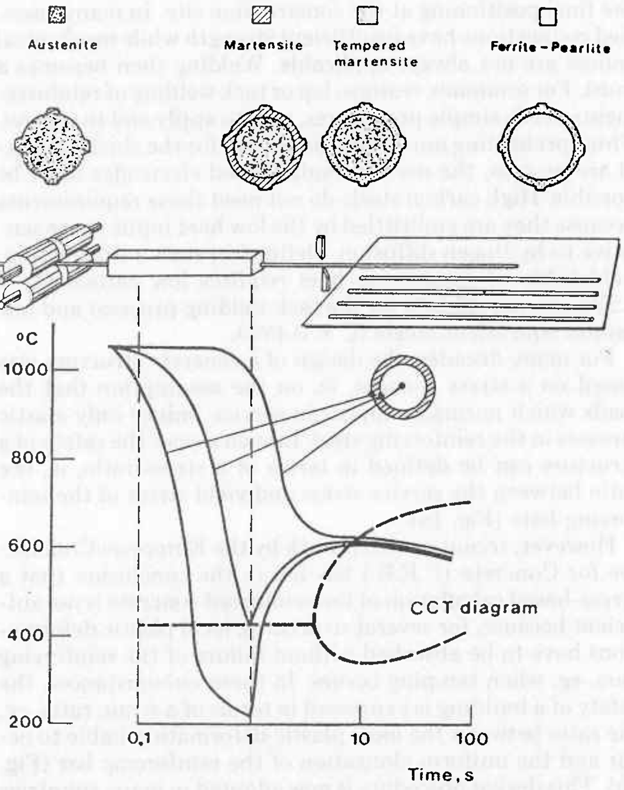
- Arbed S.A., Schifflange, Luxembourg
- S.A. Metallurgique et Miniere de Rodange-Athus, Rodange, Luxembourg
- Cockerill-Sambre S.A., Marcinelle, Belgium
- Hoogovens-IJmuiden B.V. IJmuiden, The Netherlands
- ALPA, Porcheville, France
- Manufer, Montpon, France
- Sacilor, Homécourt, France
- Sheerness Steel Co. Ltd., Sheerness, U.K.
- North Star Steel Co.,[1] Monroe, U.S.
- Broken Hill Proprietary Co., Ltd., Port Kembla, Australia
- Broken Hill Proprietary Co., Ltd., Newcastle, Australia
- Badische Stahlwerke AG, Kehl, West Germany
- Hoesch Huttenwerke AG, Dortmund, West Germany
- Max Aicher KG, Annahutte, West Germany
- Eisenwerk-Gesellschaft Maximilianshütte mbH, Haidhof, West Germany
- Arbed Saarstahl GmbH, Völklingen, West Germany
- Von Moos Stahl, Emmenbrucke, Switzerland

Under construction or planned

- Sidenor, Thessaloniki, Greece
- Norsk Jernverk a/s, Mo-I-Rana, Norway
- Elkem a/s, Christiana, Norway
- Stahl-und Walzwerke Marienhutte GmbH, Graz, Austria
- Voest-Alpine AG, Donawitz, Austria
- Lech-Stalwerke GmbH, Meitingen, West Germany
- The Tata Iron & Steel Co., Ltd., Jamshedpur, India
- Rashtriya Ispat Nigam Ltd., Visakhapatnam, India

[1] Plain carbon and alloy bars (not reinforcing bars).

Fig. 3 — Tempcore process and relationship with CCT diagram.



and depending on the cooling conditions, the austenite layer located below the quenched skin can be transformed partially or even completely to bainite. In this case, the bars produced by the process exhibit three concentric cross-sectional layers (Fig. 4): tempered martensite; bainite; and ferrite-pearlite.

Results — The main control parameters of the process are quenching time and water flow rate.

The influence of quenching time on the yield strength of the bars is shown in Fig. 5; the longer the quenching time, the higher the yield strength. Excessive quenching times must, however, be avoided because this would not insure a sufficient ductility.

The influence of water flow rate and steel composition on the yield strength of rebars is illustrated in Fig. 6. Similar relationships exist for different water pressures.

Process control is simple as the tempering temperature—defined as the maximum temperature reached by the surface of the bar during the self-tempering stage—is directly related to the mechanical properties of the bars. An example of the yield strength-tempering temperature relationships for a given chemical composition and several diameters is shown in Fig. 7. For a specified steel composition and diameter, there is an unequivocal relationship between the tempering temperature and the mechanical properties. Thus, the required mechanical properties can be developed by only varying the cooling power of the quenching installation (ie, the length of the quenching line and cooling water flow rate) to maintain the tempering temperature in a predetermined range.

The flexibility of the process is also illustrated by Fig. 7.

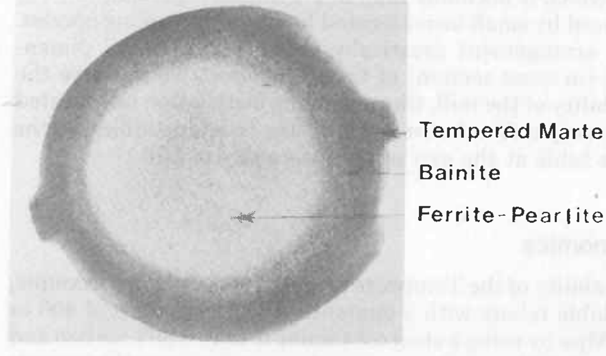
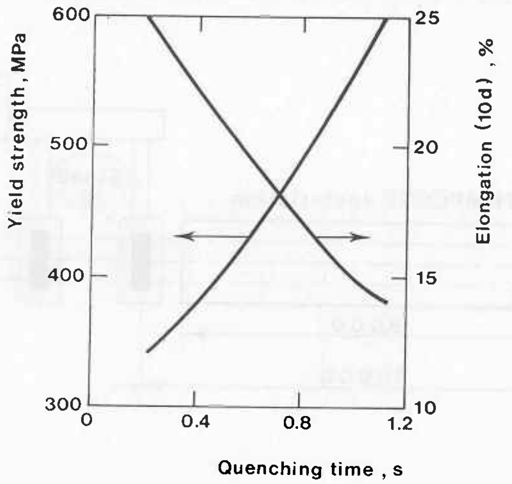


Fig. 4 — Structure of reinforcing bar produced by Tempcore process.

Fig. 5 — Effect of quenching time on yield strength and elongation.



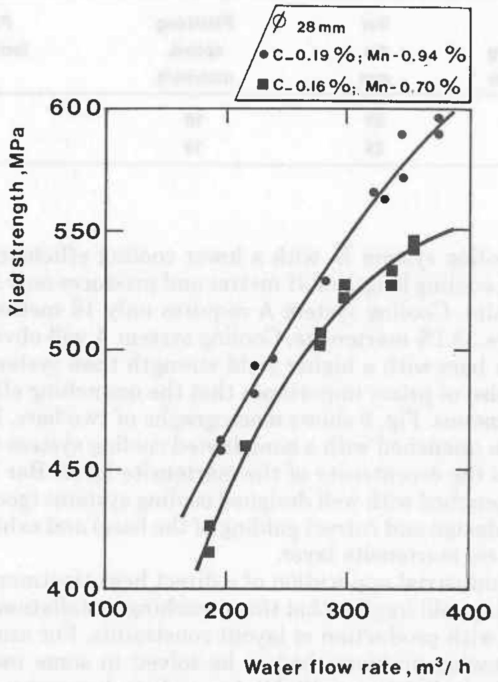


Fig. 6 — Effect of water flow rate and steel composition on yield strength.

For a given composition, a large range of yield strength can be achieved by changing only the cooling power of the quenching installation. In this example, grades having a yield strength of 400 and 500 Mpa can be produced by using the same steel (C 0.16%, and Mn 0.70%) for all diameters.

Industrial applications

The Tempcore process makes it possible to produce weldable high-strength rebars without the addition of microalloying elements. To produce high-quality reinforcing bars economically, there are several requirements which have to be fulfilled by the quenching installation.

To achieve the required properties, it is necessary to choose cooling systems which provide a high-cooling efficiency. Two types of cooling systems are compared in Table II. For the same rolling conditions and tempering tempera-

Fig. 7 — Example of yield strength-tempering temperature relationship.

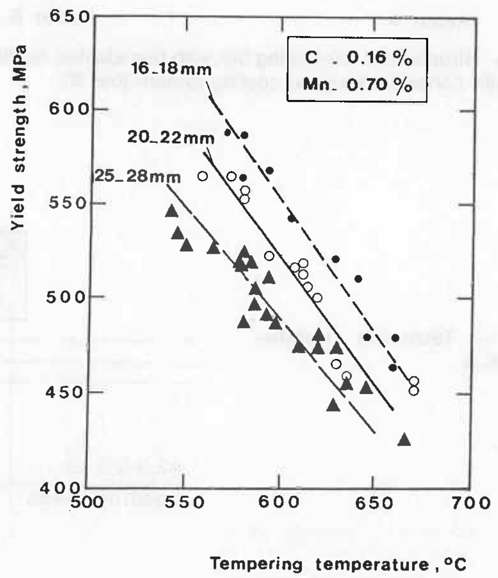


TABLE II Comparison of cooling systems

Cooling system	Bar dia, mm	Finishing speed, metres/s	Finishing temperature, °C	Tempering temperature, °C	Length of quenching line, metres	Martensite, %
A	25	10	1050	605	16.0	33.1
B	25	10	1050	605	31.0	23.6

ture, cooling system B, with a lower cooling efficiency, requires a cooling length of 31 metres and produces only 23.6% martensite. Cooling system A requires only 16 metres and produces 33.1% martensite. Cooling system A will obviously produce bars with a higher yield strength than system B.

It is also of prime importance that the quenching effect is homogeneous. Fig. 8 shows macrographs of two bars. Bar A has been quenched with a nonadapted cooling system which explains the eccentricity of the martensite layer. Bar B has been quenched with well designed cooling systems (good hydraulic design and correct guiding of the bars) and exhibits a concentric martensite layer.

The industrial application of a direct heat treatment in a hot rolling mill implies that the quenching installation must comply with production or layout constraints. For example, the following problems had to be solved in some installations: short distance available for cooling; low-water availability; a rapid change of products, grades and sections; and installation of the quenching line in difficult areas, ie, in multi-line mills.

Examples of industrial installation — In mill A (Fig. 9), the constraints were: small diameters (down to 8 mm) rolled at a relatively high speed (up to 13 metres/s), and a small distance available for cooling between the finishing stand and the existing dividing shears.

These constraints were overcome by employing a high

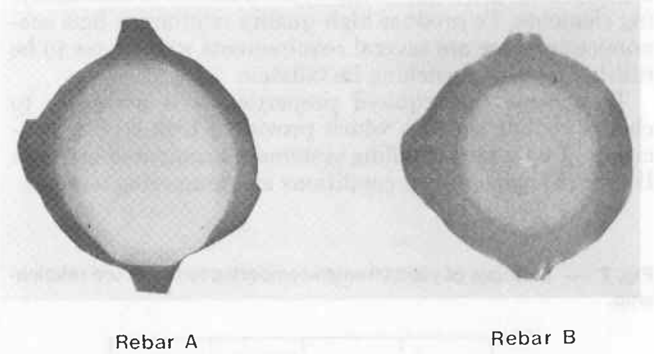


Fig. 8 — Structure of reinforcing bar with nonadapted cooling (bar A) and with correctly designed cooling system (bar B).

cooling efficiency with a suitable dragging force within the cooling system. Short cooling nozzles were used with high water flow rates of up to 60 cu metres/hr and a quenching length of 1 metre. As a result, it was possible to limit the length of the quenching installation to 9 metres.

In the case of mill B (Fig. 10), the constraints were: limited availability of water; and the requirement to perform fast changes between Tempcore products and other products such as flats. In this situation, long cooling nozzles (approximately 3.5 metres) fed at a relatively high pressure (12 kg/sq cm) with low water flow rates (approximately 12 cu metres/hr and a quenching length of 1 metre) were used to limit the total water flow rate to approximately 280 cu metres/hr. The production rate was 100 tons/hr. Rapid product changes were accomplished by installing the quenching system on a large frame, together with troughs equipped with driven rolls. The frame moves on rails and can be displaced laterally to bring the desired system into the passline. Switching times as short as 3 to 5 min have been obtained. Moreover, this system also has the advantage of being operated without a crane.

In another installation, a multi-line mill, the constraints were the erection of quenching equipment in an area already crowded with other mill equipment without altering the flexibility of the mill. In this case, a large water collecting box, which is normally used in a Tempcore installation, was replaced by small boxes located between the cooling nozzles. This arrangement drastically reduced the overall dimensions (in cross-section) of the installation. To preserve the flexibility of the mill, the quenching installation was located in a new passline between one of the finishing mills and the roller table at the exit of the intermediate mill.

Economics

The ability of the Tempcore process to produce, for example, weldable rebars with a guaranteed yield strength of 400 or 500 Mpa by using a steel containing 0.15 to 0.20% carbon and 0.60 to 0.80% manganese, provides a savings over the conventional processes which produce strain hardened bars through an additional processing step, or as-rolled bars which use microalloying elements.

Additional economic advantages are gained from the use of only one steel composition for all diameters and different

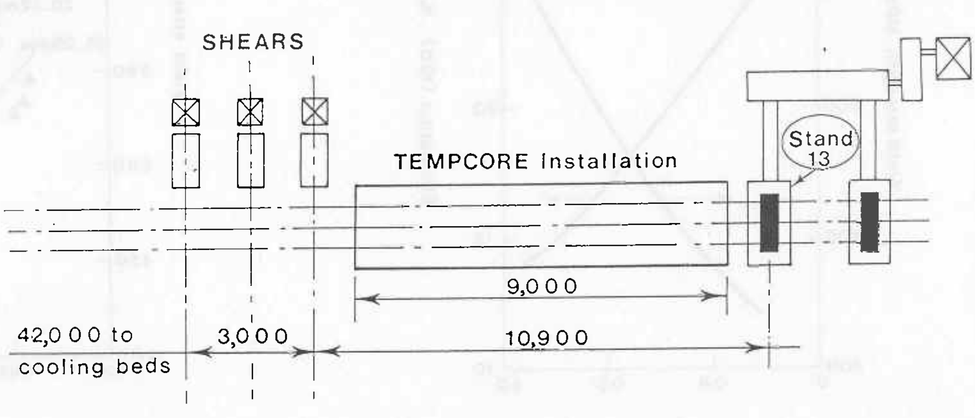


Fig. 9 — Tempcore installation—mill A.

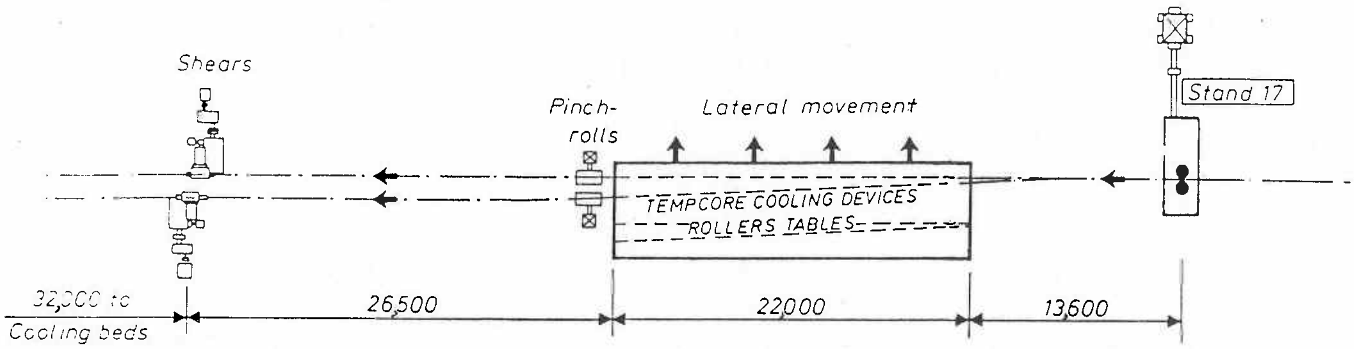


Fig. 10 — Tempcore installation—mill B.

product grades. The steelmaking operation is simplified and the number of off-grade heats is reduced. Moreover, most off-grade heats can be saved due to the flexibility of the Tempcore process: the cooling power of the quenching installation can be changed to accommodate the compositon of the steel. In some cases, the process facilitates hot charging leading to an increase in reheat furnace capacity and a decrease in energy costs.

Operating costs are low, generally in the range of $0.2 to $0.4/ton. A maximum of $1/ton is reached when thermomechanical treatment (precooling before the finishing mill) has to be used to reduce the length of the quenching installation.

Summary

High yield strength together with good weldability and excellent ductility are the characteristics of modern reinforcing bars. Conventional processes cannot fulfill these requirements economically and a new technology has been developed—the Tempcore process.

Examples of industrial applications are given which demonstrate that the process is able to fulfill the multiple technological requirements linked to the implementation of a direct heat treatment in a hot rolling mill. The process is economically and technically feasible in almost all bar mills.