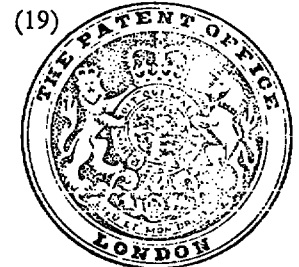


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(54) IMPROVED CONCRETE REINFORCING ELEMENTS AND REINFORCED COMPOSITE INCORPORATING SAME

(71) We, AUSTRALIAN WINE INDUSTRIES PROPRIETARY LIMITED, a company incorporated under the laws of the State of Victoria, Australia, of 140 William Street, Melbourne, Victoria, Commonwealth of Australia, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to reinforcing elements for concrete and other castable materials such as plastics and ceramics, and to a process for manufacturing such reinforcing elements. The invention also relates to a reinforced composite incorporating such reinforcing elements.

It is known to incorporate short lengths of steel wire in concrete to improve its properties. Such a reinforced composite is described in the specification of Australian Patent No. 290,468. A related reinforced composite comprising a castable matrix mass, such as concrete, incorporating discontinuous reinforcing filaments having a non-round cross-section with a width and thickness ratio of not greater than five is disclosed in U.S. Patent No. 3,650,785.

In each of the above concrete-steel fibre composites, the increase in strength has been limited by the poor mechanical and chemical bond between the steel fibres and the cement matrix. The steel fibres tend to pull out of the matrix long before the fibres reach their ultimate strength.

Attempts have been made to overcome the problem but in each case the modification has been impractical or the bond strength increased only marginally. One modification involved the use of longer steel fibres but such were found too difficult to handle and mix in the matrix. Similarly, the fibres have been

chemically treated, coated or crimped in an attempt to increase bond strength but with little success.

German patent publication 2,042,881 suggests that the wire ends be bent or shaped, but this tends to reduce mixability and reduces the effective fibre length.

It is the primary object of the invention to provide an improved form of reinforcing element which is formed to improve the locking effect between the element and the matrix it reinforces.

The invention provides, in a first aspect, reinforcing fibres for materials such as concrete, mortar, glass, stabilised materials, plastics or ceramics, each of said reinforcing fibre for castable matrix materials, each of said fibres comprising a shank portion of substantially uniform generally rectangular cross-sectional area, said shank having an average width of about 0.010 to about 0.060 inches and an average thickness of about 0.005 to about 0.03 inches, and enlarged portions at each end of the shank having cross-sectional areas at least about 1.5 times larger than the cross-sectional area of shank, the ratio of the thickness of the enlarged portions to the thickness of the shank being from 1.5 to 6, and the mean length of all said fibres being about $\frac{1}{2}$ to about 3 inches.

Preferably the end portions are larger in both longitudinal and transverse planar cross-sections thereof.

The interfacial shear stresses in discontinuous filaments or fibres incorporated in a low strength brittle matrix are maximum at the fibre ends. By enlarging the end of the filament or fibre, especially in both cross-sections, the locking effect at the ends is improved due to the enlargement of the ends relative to the shank and accordingly the

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reinforcing effect of the fibre should be increased using more or all of its available tensile strength.

5 It is preferred that the end portions of the fibre be enlarged by deformation to suitably shape the end and for this reason the fibre is preferably made from a metal, plastics or other material capable of being permanently deformed or shaped. In one preferred form 10 each enlarged end portion comprises a projection extending from the face of the shank, the projection having a generally parabolic, or hyperbolic profile when viewed in longitudinal cross-section elevation, and a generally rectangular cross-section elevation. 15

Where the material being reinforced is concrete or mortar, the fibres are preferably of steel, although other metals or metallic alloys having the required high tensile strengths, e.g., 20 above 30,000 psi, may be used if desired.

The fibres may have any desired cross-sectional configuration and are preferably in the form of short lengths of wire-like material with the shank thereof plain and of substantially uniform unvarying cross-section. The 25 gauge tensile strength and configuration of the fibre shank is selected according to the desired performance and may include gauges and configurations as disclosed in the prior art referred to hereinabove. 30

The low strength brittle matrix material may be any of the conventional castable curable or hardenable matrix material but preferably is a cementitious castable matrix mass such as concrete or plain mortar. Most 35 preferably the cementitious matrix mass is based on Portland cement.

Suitable cementitious compositions are disclosed in Kirk-Othmer, *Encyclopedia of Chemical Technology*, Second Edition, 40 Volume 4, pages 684—710 (1964), the disclosure of which is hereby incorporated by reference.

The reinforcing fibres, which are discontinuous, may be chosen from a wide variety 45 of materials, including reinforcing glass fibres, reinforcing nylon fibres, reinforcing titanium fibres, reinforcing tungsten fibres, reinforcing copper fibres, reinforcing lead fibres, reinforcing steel fibres and reinforcing aluminum 50 fibres. Of course, alloys of the above-mentioned metals may also be utilized if desired.

The reinforced composite structure of the present invention is made by mixing the reinforcing fibres in the castable matrix. It is preferable to uniformly distribute the fibres throughout the matrix, although some fibre agglomeration can be tolerated. Normally, the 60 reinforcing fibres are used in an amount of from $\frac{1}{2}$ to 5% by absolute volume, preferably about 1—2% by absolute volume. In the case of Portland cement, concrete or mortar matrixes and steel reinforcing fibres, the steel 65 fibres will be used in an amount of from about

3—6% by weight of the total composition.

The castable matrix is then cured or hardened under appropriate conditions, depending upon the nature of the matrix material. A chemical hardener or curing agent may be used 70 in the case of thermosetting polymers. For cementitious products, the normal cure will be a simple time cure (i.e. 1—15 days or so) at ambient conditions, or even at elevated 75 temperatures, normally in the presence of moisture.

In a second aspect of the invention, there is provided a method of forming the reinforcing fibres of metal or other material capable of being permanently deformed or shaped 80 comprising the steps of a strip of said material having a width greater than $\frac{1}{4}$ " by means of a roll forming operation to form a shaped strip having enlarged edges the shaped strip having a width of about $\frac{1}{4}$ to about 3 inches and a 85 thickness between the enlarged edges of about 0.005 to about 0.03 inches, and the enlarged edges having a thickness of 1.5 to 6 times that of the strip intermediate the enlarged edges, and there after shearing the strip transversely to produce reinforcing fibres having a width of 0.01 to 0.06 inches may be performed, such as folding or otherwise deforming the edge of the strip or reducing the cross-sectional area of the central portion of the 90 strip to enlarge the edges relative to the central portion. These operations will be described in more detail below. 95

A preferred method of forming reinforcing fibres comprises forming a plurality of strips simultaneously before the roll forming operation by longitudinally slitting a wider strip. The roll forming and shearing operations are then carried out on the plurality of narrow strips with the strips running in parallel. 100

A single shearing device may be used to shear said plurality of formed strips simultaneously and preferably comprises a multi-toothed rotary cutter running with a slight clearance against a fixed cutter. 105

Some preferred embodiments of the invention are described by way of example with reference to the accompanying drawing in which:— 110

Figure 1 is a perspective view of a reinforcing fibre embodying the invention; 115

Figure 2 shows the steps in a simple method of enlarging the edges of a strip prior to forming the fibre of Fig. 1;

Figure 3 is a side elevation of an alternative form of fibre having a double-folded enlarged end; 120

Figure 4 is a schematic diagram of an apparatus for forming fibres from a wide strip;

Figure 5 shows the steps in the edge enlarging method performed by the apparatus of Figure 4 together with schematic representations of the preferred roll forming profiles used; 125

Figures 6 and 7 are fragmentary side eleva- 130

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tions of two alternative forms of strip edge enlargement;			
Figure 8 is a schematic representation of an apparatus for achieving the edge enlargements of Figures 6 and 7;	5		
Figure 9 is an enlarged fragmentary view of the roller profiles used to achieve the edge enlargement;			
Figure 9A is an enlarged view of one end of a reinforcing fibre produced by shearing a strip having the edge enlargement shown in Figure 6, and	10		
Figures 10 to 13 are representations of alternative forms of edge enlargements.			
Figure 1 shows one form of steel reinforcing fibre 1 which as enlarged ends defined by the end portions 2 of the fibre 1 being folded onto its shank 3. The shank 3 is plain and of uniform unvarying cross-section from about 0.005 to 0.030 inch thick, about 0.010 to 0.060 inch wide and from about 0.5 to 2 inches or longer in length. Each fold 2 may be from about two to four times the thickness of the fibre 1, preferably from 0.020 to 0.050 inch. The dimensions recited here are merely exemplary since they must be selected in accordance with the fibre material, the material to be reinforced thereby and the performance desired.	15		
The fibre shown in Figure 1 is made from a narrow strip of steel that has its edges folded over onto itself. The steps in one simple method of edge folding are shown in Figure 2. A narrow strip as shown view (a) is fed into a forming roll to turn the edges of the strip at right angles as shown in view (b). The strip then enters a further set of forming rolls that turns the turned edge further inwardly through about 45° as shown in view (c). The turned edges are then flattened by a further set of forming roll as in view (d).	20		
A strip with double folded edges as shown in Figure 3 may be produced by repeating the above steps on the strip shown in view (d):	25		
After the edge-folding operation, the strip is fed to an apparatus for transversely shearing the strip into fibres 1. If a plurality of strips are used, the strips can be separated for individual shearing operations. It is also possible to shear the plurality of strips simultaneously, and in that instance the most suitable shearing device is a multi-toothed rotary cutter running with a slight clearance against a fixed cutter or anvil. However, other types of cutters, including other types of rotary cutters, are suitable for use in forming the fibres of the present invention.	30		
The above described simple method of edge folding is satisfactory for individually fed single strips but since it requires horizontally oriented rollers for the edge turning operations, it is not satisfactory for edge folding a plurality of narrow strips slit from a wide strip and running in side by side relationship	35		
during the roll forming and shearing operations.	40		
An apparatus for performing edge roll forming operations on several narrow strips slit longitudinally from a wide supply strip is shown schematically in Figures 4 and 5. The supply strip 4 is drawn from a coil 5 suitably mounted on a pay off stand. The strip 4 passes over a guide roll 6 and through a strip splitter 7 comprising a plurality of slitting rolls that slit the strip 4 into a plurality of narrow strips 8 of the desired width(s). The construction and mode of operation of the strip splitter 7 does not form part of this invention and any conventional splitter, such as described in the copending application referred to above, may be used.	45		
Each narrow strip 8 then passes through a roll 9 formed with a profile that imparts a false bend 10 to each strip 8, as shown in Fig. 5. The reason for this is to space the adjacent edges of the narrow strips 8 sufficiently to allow the positioning of a positive guide means (not shown) for guiding the strips 8 into the first roll forming stage. A false bend sufficient to space adjacent strip edges by between 0.015 to 0.020 inch would seem to be satisfactory	50		
The first roll forming stage (d) comprises upper and lower rollers 11 and 12 each having a profile that imparts a 45° bend to the edge portions 13 of each strip 8 and flattens the false bend 10 therein. (See Fig. 5). The figure shows part of the profile of the rolls 11 and 12 suitable for achieving this roll forming operation at one edge of the strip. The second to fifth roll forming stages (e to h) are also achieved by profiled rolls 13 and 14, 15 and 16, 17 and 18 and 19 and 20 respectively and the relevant profile portions of these rolls are also shown in Figure 5.	55		
In the second roll forming stage (e), the edge portions 13 are turned through a further 45° to 90°. The third stage (f) forms a 45° bend 21 in the strip inwardly of the edge portion 13 while the fourth stage (g) folds the portions 13 through a further 45°. The fifth stage (h) flattens the bend 21 and places the portion 13 in intimate contact with the strip surface. The completely edge folded strip 22 is then in the same condition as in stage (d) of Figure 2.	60		
The plurality of strips 22 are fed by feed rolls 23 between guide plates 24 into a rotary cutter 25 that runs with a slight clearance against a fixed cutter or anvil 26 to shear the strips into reinforcing fibres of the desired width. A chute 27 collects the fibres as they are formed.	65		
It will be evident that the single strip and multiple strip methods of manufacturing reinforcing fibres described above not only result in an enlarged end fibre but achieve this in a particularly novel way. While the single strip	70		
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method would not be adequate for high volume work it may be possible to utilize this shorter method by separating the slit strips in a direction transverse to their direction of movement and passing each strip through a separate three

5 step roll forming operation, followed by a separate or common shearing operation. If desired, the edges of the strip may be folded onto opposite surfaces of the strip.

10 Generally parabolic and hyperbolic strip edge enlargement profiles are shown in Figures 6 and 7, respectively. This latter form of enlargement is achieved, as shown in Figures 8 and 9, by hot or cold edge rolling a steel strip to deform the edges and thereby enlarge them. The strip is constrained between two

15 vertically spaced rolls 30 while two laterally spaced rolls 31 bear on the small edge portions of the strip projecting from the sides of rolls 30. The edges 32 of rolls 30 may be rounded or otherwise profiled while the rolls 31 have central grooves 33 of a desired shape which receive the edges of the strip. The required force applied via the rolls 31

20 act to deform or upset the edges of the strips to achieve enlargement thereof.

This alternative method of edge enlargement has the advantage that the shape of the enlargement can take many different forms whereas the shapes available from the edge folding process are limited. The edge-rolled shape may for example be such as to provide a form of controlled interface rupture of the fibres when the reinforced composite is stressed so that the characteristics of the composite can be positively controlled.

30 Following the edge deformation process, the strip is sheared as in the previous embodiments. The strip fed to the edge rolling arrangement may be taken from a storage coil having been slit from a wide strip and recoiled previously, or slit strips may be vertically separated as described above and fed into the required number of edge rolling arrangements.

45 The resulting fibre shown in Figure 9A therefore has a plain rectangular section shank 34 and raised projections 35 extending from opposite faces of the fibre. As viewed from the side, each of the projections 35, is generally hyperbolic in configuration. The sides 36 of the fibre are plain and generally perpendicular to the opposite faces due to shearing operation.

50 The alternative edge profiles shown in Figures 10 to 13 are included in this specification to illustrate that the forms described above are merely exemplary.

55 The strip profiles shown in Figures 10 and 11 may be achieved by longitudinal rolling of the strip by means of suitably profiled rollers.

60 The edge profile of Figure 12 is achieved by roll forming operations similar to those used in the first two embodiments. The roller profiles necessary to achieve this form will be self-evident.

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The profile of Figure 13 is achieved by rolling up the folded edge of the strip at stages (d) or (h) of the previous embodiments.

In general, the dimensions of the shank and the dimensions of the enlarged ends will be governed by a number of design factors, as well as the selection of the matrix material and the reinforcing fibres material. It is generally preferred that the fibre aspect ratio (that is, the ratio of fibre length to diameter or width) be no greater than 100, as greater aspect ratios are somewhat more difficult to handle. Normally, the shank will have a thickness of about 0.005 to about 0.03 inches, a width of about 0.01 to about 0.06 inches, and a length of at least 0.5 inches. Normally, the length will be no greater than about 3 inches, preferably no greater than about 2 inches.

70 The relationship between the dimensions of the enlarged ends and the dimensions of the shank are a significant feature of the present invention. When the enlarged end is formed by a folding operation, the enlarged end will generally have a thickness which is a multiple of the thickness of the shank, although an additional flattening step or the like could be performed if desired to change this relationship. Normally the folded enlarged end thickness will be about 2—4 times the thickness of the shank.

85 Greater flexibility of the enlarged end-shank ratio can be obtained with the method of edge deformation by edge rolling. To obtain the maximum energy-absorbing properties from a composition of a matrix such as concrete or cement and reinforcing discontinuous filaments of steel or the like, it is desired that the interfacial bond between the matrix material and the reinforcing fibre be ruptured just prior to the point where the fibres are subjected to a tensile stress which is in excess of their ultimate tensile strength. This stress, of course, depends upon the particular material of which the filaments are, made, as well as the dimensions of the filament shank. The enlarged ends of the filament can be chosen of such size and design as to permit interfacial movement of the filament in the matrix just prior to filament rupture. This has the effect of permitting greater amounts of energy to be absorbed in the composite structure, as a sudden rupture of the filament without such interfacial movement is normally rapidly propagated throughout the composite structure. Composite reinforced structures utilizing the reinforcing filaments permitting the interfacial movement described above have particular application for uses where the structures are subjected to high impact loadings. For some such composite compositions, the ratio of enlarged end thickness to shank thickness may be as small as 1.5, but normally such ratio will be about 2.

On the other hand, when the design com-

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siderations dictate that the fibres should rup-
 ture prior to significant interfacial slippage, the
 ratio of enlarged end thickness to shank thick-
 ness may be much higher, e.g. as high as 4
 or 6. Such higher thickness ratios are generally
 difficult to obtain by edge rolling, and the fold-
 ing technique will generally be used.

The length of each enlarged end portion
 of the reinforcing fibre may vary as desired.
 Normally, for economical reasons the length
 of the enlarged portions will be chosen as
 small as possible. Bearing this in mind, there-
 fore, the shank will normally be at least 70%
 of the length of the reinforcing fibre, prefer-
 ably at least 80% and more preferably at least
 90% of the reinforcing fibre length.

It will be appreciated that, because of the
 configuration of their enlarged ends, each of
 the reinforcing elements described herein lend
 themselves to easy handling as distinct from
 many of the prior art fibres which may have
 sharp ends and are thus prone to cause injury
 when handled.

The strip or even the individual fibres may
 be heat treated or chemically treated, using
 conventional treatment procedures prior to or
 after the rolling or shearing operation, depend-
 ing upon the intended end use of the reinforcing
 elements.

In using reinforcing fibres embodying the
 invention to reinforce a castable material, the
 necessary fibre content of the required strength
 and enlarged end characteristics is experi-
 mentally or otherwise determined and the
 fibres admixed with the material prior to cast-
 ing. Where the material is concrete or mortar,
 the quantity of fibres may be selected to be
 sufficient to inhibit the propagation of cracks
 in the reinforced composite.

As already mentioned, the enlargement of
 the ends of the filament or fibre in any one
 of the manners described serves to increase the
 locking effect between the ends of the fibres
 and the cast material, accordingly the reinforc-
 ing effect of the fibre should be increased by
 using up to all of the filament's available
 tensile strength. Table 1 dramatically illus-
 trates the increase in the locking effect. The
 use of fibres embodying the invention may
 result in the achievement of equivalent physi-
 cal tensile strength using a lower proportion
 of fibres than in the prior art thus decreasing
 the cost for a given strength or improved
 matrix strength for the same proportion of
 fibres than in the prior art.

The reinforcing effect of the end-enlarged
 fibres of the present invention is difficult to
 directly measure, due to a number of factors,
 including the random distribution of fibres in
 the matrix, possible fibre orientation in the
 matrix, test specimen size effects, and the like.
 The following pull-out tests illustrate the rein-
 forcing effect obtained with the present inven-
 tion.

In the pull-out or extraction tests reported
 in Table 1 below, 10 fibres were embedded in
 a 2.5:1 Portland cement mortar, with each fibre
 being at least $\frac{1}{8}$ inch distance from the other
 fibres. The test specimen was wet cured for
 seven days at room temperature. Then the
 fibres were individually extracted from the test
 specimen, with the values reported in Table
 1 being the average of the ten extractions (or
 breaks, as the case may be). The single fold
 enlarged ends were about 0.02 inches thick
 and about 0.05 inches long. The double fold
 ends were about 0.03 inches thick and about
 0.06 inches long.

TABLE 1

Pull-out Tests - Comparison of Plain Fibres and
 Fibres with End Enlargement

Fibre	Embed- ment Depth	Nominal cross- section dimensions	Average bond strength lb/ins ² . % increase		Average wire stress at pull-out or break lb/ins ² . % increase	
Plain Rectangular	0.5"	0.030" × 0.010"	397	—	52,000*	
Rectangular with single fold end	0.375"	0.030" × 0.010"	699	76%	70,200*	33.5%
Rectangular with double fold end	0.375"	0.030" × 0.010"	999	152%	101,500**	93%

* All fibres pulled out of the mortar.

** Eight fibres broke off while two fibres pull out of the mortar.

The average tensile strength of the fibre was 103,00 lbs/ins. The fibres were manufactured by shearing 0.010" strip into 0.030" wide fibres.

- 5 The dramatic increase in the locking effect introduced by the use of enlarged end fibres indicates that it may be necessary to produce fibres from high tensile steel in order to obtain the full benefit of the predicted increase in strength of cast materials incorporating such fibres. For certain high tensile steels, it may not be possible to use the edge folding technique but it is believed that the edge rolling method described will produce satisfactory high tensile fibres.

WHAT WE CLAIM IS:—

1. Reinforcing fibres for castable matrix materials, each of said fibres comprising a shank portion of substantially uniform generally rectangular cross-sectional area, said shank having an average width of about 0.010 to about 0.060 inches and an average thickness of about 0.005 to about 0.030 inches, and enlarged portions at each end of the shank having cross-sectional areas at least about 1.5 times larger than the cross-sectional area of the shank, the ratio of the thickness of the enlarged portions to the thickness of the shank being from 1.5 to 6, and the mean length of all said fibres being about $\frac{1}{4}$ to about 3 inches.

2. Fibres according to claim 1, wherein the enlarged end portions are larger than the shank in both the longitudinal and any transverse planar cross-sections thereof.

3. Fibres according to claim 1 or 2, wherein the end portions comprise portions of the fibre folded upon itself, with said end portions extending generally parallel to and at least closely adjacent to the fibre.

4. Fibres according to claim 3, wherein the thickness of each folded portion is from two to four times the thickness of the fibre.

5. Fibres according to any one of claims 1 to 4, wherein said fibre is of steel.

6. Fibres according to claim 1 or 2, wherein longitudinal cross-sectional elevations of the end portions include oppositely directed integral projections of generally rounded shape.

7. Fibres according to claim 1, 2 or 6, wherein each enlarged portion comprises a raised projection extending from at least one face of the shank and at least near each end of the fibre, each projection having a generally parabolic longitudinal cross-section elevation and a generally rectangular transverse cross-sectional elevation.

8. Fibres according to claim 1, 2 or 6, wherein each enlarged portion comprises a projection extending from at least one face of the shank and at least near each end of the fibre, each projection having a generally hyperbolic profile when viewed in the longitudinal cross-section elevation and a generally rectangular transverse cross-sectional elevation.

9. A method of forming reinforcing fibres according to any one of claims 1 to 6 for castable matrix materials, said fibres of material capable of being permanently deformed or shaped, said method comprising the steps of shaping a strip of said material having a width greater than $\frac{1}{4}$ " by means of roll forming operations to form a shaped strip having enlarged edges the shaped strip having a width of about $\frac{1}{4}$ to about 3 inches and a thickness between the enlarged edges of about 0.005 to about 0.03 inches, and the enlarged edges having a thickness 1.5 to 6 times that of the strip intermediate the enlarged edges and thereafter shearing the strip transversely to produce reinforcing fibres having a width of 0.01 to 0.06 inches.

10. A method according to claim 9, wherein said roll forming operations fold the edges of said strip over onto the surface of the strip.

11. A method according to claim 10, wherein the thickness of the folded edges are between about two and four times the thickness of the strip.

12. A method according to claim 10 or 11, wherein said roll forming operations include the following steps

- (a) turning the edge portions of the strip through about 90°;

- (b) thereafter turning the edge portions through a further acute angle towards the strip, and

- (c) thereafter flattening said edge portions onto the strip.

13. A method according to claim 10 wherein a plurality of narrow strips are obtained from a wider strip by means of a strip slitting operations, said roll forming operations being performed on said narrow strips while they run side by side, said roll forming operations including:

- (a) guiding the strips into a first roll forming stage in which the edge portions are bent through about 45°;

- (b) thereafter bending the edge portions through a further 45° to 90°;

- (c) thereafter bending the strip at positions inwardly of the edge portions, through about 45°;

- (d) thereafter bending said edge portions through a further 45°, and

- (e) thereafter flattening the bend introduced by operation (c) to place the edge portions into contact or close parallel proximity with the strip.

14. A method according to claim 13, wherein, in order to facilitate guidance of said strips, a small false bend is introduced into the centre of said strip to space their edges sufficiently to allow insertion of or positive guide means therebetween.

15. A method according to claim 9, wherein said roll forming operations include the application of a rolling force perpendicularly to the edge of the strip while said strip is generally



The average tensile strength of the fibre was 103,00 lbs/ins. The fibres were manufactured by shearing 0.010" strip into 0.030" wide fibres.

- 5 The dramatic increase in the locking effect introduced by the use of enlarged end fibres indicates that it may be necessary to produce fibres from high tensile steel in order to obtain the full benefit of the predicted increase in strength of cast materials incorporating such fibres. For certain high tensile steels, it may not be possible to use the edge folding technique but it is believed that the edge rolling method described will produce satisfactory high tensile fibres.

WHAT WE CLAIM IS:—

1. Reinforcing fibres for castable matrix materials, each of said fibres comprising a shank portion of substantially uniform generally rectangular cross-sectional area, said shank having an average width of about 0.010 to about 0.060 inches and an average thickness of about 0.005 to about 0.030 inches, and enlarged portions at each end of the shank having cross-sectional areas at least about 1.5 times larger than the cross-sectional area of the shank, the ratio of the thickness of the enlarged portions to the thickness of the shank being from 1.5 to 6, and the mean length of all said fibres being about $\frac{1}{4}$ to about 3 inches.

2. Fibres according to claim 1, wherein the enlarged end portions are larger than the shank in both the longitudinal and any transverse planar cross-sections thereof.

3. Fibres according to claim 1 or 2, wherein the end portions comprise portions of the fibre folded upon itself, with said end portions extending generally parallel to and at least closely adjacent to the fibre.

4. Fibers according to claim 3, wherein the thickness of each folded portion is from two to four times the thickness of the fibre.

5. Fibres according to any one of claims 1 to 4, wherein said fibre is of steel.

6. Fibres according to claim 1 or 2, wherein longitudinal cross-sectional elevations of the end portions include oppositely directed integral projections of generally rounded shape.

7. Fibres according to claim 1, 2 or 6, wherein each enlarged portion comprises a raised projection extending from at least one face of the shank and at least near each end of the fibre, each projection having a generally parabolic longitudinal cross-section elevation and a generally rectangular transverse cross-sectional elevation.

8. Fibres according to claim 1, 2 or 6, wherein each enlarged portion comprises a projection extending from at least one face of the shank and at least near each end of the fibre, each projection having a generally hyperbolic profile when viewed in the longitudinal cross-section elevation and a generally rectangular transverse cross-sectional elevation.

9. A method of forming reinforcing fibres according to any one of claims 1 to 6 for castable matrix materials, said fibres of material capable of being permanently deformed or shaped, said method comprising the steps of shaping a strip of said material having a width greater than $\frac{1}{4}$ " by means of roll forming operations to form a shaped strip having enlarged edges the shaped strip having a width of about $\frac{1}{4}$ to about 3 inches and a thickness between the enlarged edges of about 0.005 to about 0.03 inches, and the enlarged edges having a thickness 1.5 to 6 times that of the strip intermediate the enlarged edges and thereafter shearing the strip transversely to produce reinforcing fibres having a width of 0.01 to 0.06 inches.

10. A method according to claim 9, wherein said roll forming operations fold the edges of said strip over onto the surface of the strip.

11. A method according to claim 10, wherein the thickness of the folded edges are between about two and four times the thickness of the strip.

12. A method according to claim 10 or 11, wherein said roll forming operations include the following steps

- (a) turning the edge portions of the strip through about 90°;
(b) thereafter turning the edge portions through a further acute angle towards the strip, and
(c) thereafter flattening said edge portions onto the strip.

13. A method according to claim 10 wherein a plurality of narrow strips are obtained from a wider strip by means of a strip slitting operations, said roll forming operations being performed on said narrow strips while they run side by side, said roll forming operations including:

- (a) guiding the strips into a first roll forming stage in which the edge portions are bent through about 45°;
(b) thereafter bending the edge portions through a further 45° to 90°;
(c) thereafter bending the strip at positions inwardly of the edge portions, through about 45°;
(d) thereafter bending said edge portions through a further 45°, and
(e) thereafter flattening the bend introduced by operation (c) to place the edge portions into contact or close parallel proximity with the strip.

14. A method according to claim 13, wherein, in order to facilitate guidance of said strips, a small false bend is introduced into the centre of said strip to space their edges sufficiently to allow insertion of or positive guide means therebetween.

15. A method according to claim 9, wherein said roll forming operations include the application of a rolling force perpendicularly to the edge of the strip while said strip is generally



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constrained except at its edge portions, said edge portions being deformed to thereby enlarge same.

5 16. A method according to claim 15, wherein said enlarged edge portions have oppositely directed projections of rounded transverse cross-sectional elevation.

10 17. A method according to claim 15 or 16, wherein a plurality of narrow strips are obtained from a wider strip by means of a strip slitting operation, said strips being separated in a direction transverse to the direction of travel thereof prior to said edge rolling operation.

15 18. A method according to claim 15, 16 or 17, wherein a plurality of narrow strips are obtained from a wider strip by means of a strip slitting operation, said strips being re-rolled and subsequently individually fed through said edge rolling operation.

20 19. A reinforced cast composition, said composition comprising at least one cured or hardened matrix material and at least a reinforcing amount of reinforcing fibres, said fibres being as defined in any one of claims 1 to 8, the enlarged portions being larger than the shank by an amount at least sufficient to improve the resistance of said enlarged portions to extraction from said matrix upon the application of separating forces.

25 20. A composition as claimed in claim 19, wherein the resistance to extraction from said matrix upon the application of separating forces of said enlarged portions is at least 25% higher than the resistance to said extraction of a corresponding length of said shank portion.

30 21. A reinforced cast composition, said composition comprising at least one cured or hardened matrix material and at least a reinforcing amount of reinforcing discontinuous fibres, said fibres being as defined in any one of claims 1 to 8, the enlarged portions being larger than the shank portions by an amount

at least sufficient to improve the resistance of said enlarged portions to extraction from said matrix, provided, however, that the size of the enlarged area is less than the size required to cause fibre shank rupture rather than fibre-matrix interface slippage upon the application of separating forces. 45 50

22. A composition according to claim 19, 20 or 21 wherein from 0.5 to 5% by absolute volume of said reinforcing fibres is used.

23. A composition according to claim 19, 20 or 21, wherein from 1 to 2% by absolute volume of said reinforcing fibres is used. 55

24. A composition according to claim 23, wherein said matrix material is a cementitious material. 60

25. A composition according to claim 24, wherein said enlarged portions are about twice as large in transverse cross-sectional area than said shank portions.

26. A composition according to any one of claims 19 to 25, wherein said discontinuous fibres are mixed into and randomly spaced throughout said matrix material. 65

27. Reinforcing fibres substantially as described with reference to Figure 1 or 3 or 6 or 7 and 9A or 10 or 11 or 12 or 13 of the accompanying drawings. 70

28. A method of forming reinforcing fibres substantially as described with reference to Figure 2 or 5 or 8 and 9 or 10 or 11 or 12 or 13 of the accompanying drawings. 75

29. A reinforced cast composition according to any one of claims 19 to 26 wherein the reinforcing fibres are as defined in claim 27.

30. Fibres according to claim 1 wherein the ratio of the thickness of the enlarged portions to the thickness of the shank is from 2 to 4. 80

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