(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 218 167 A1

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: 86113353.6

(22) Date of filing: 29.09.86

(51) Int. Cl.⁴: C21D 7/04 , C21D 8/06 , //C22C38/04

(30) Priority: 30.09.85 JP 214770/85
30.09.85 JP 214771/85
30.09.85 JP 214977/85

(43) Date of publication of application: 15.04.87 Bulletin 87/16

(84) Designated Contracting States: BE DE FR

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(54) **High tensile strength drawn steel wire with improved ductility.**

(57) The high tensile drawn steel wire of the present invention contains 0.4 to 1.0% by weight of C, 2.0% or less by weight of Si, 0.2 to 2% by weight of Mn, 0.02% or less by weight of P, 0.02% or less by weight of S, and 0.01% or less by weight of N, and has a strength of 130 kgf/mm² or more and a residual compression stress of between (0.05 σ + 23) and (0.35 σ + 28) kgf/mm² on its surface, depending on its strength σ. The steel wire has excellent ductility. The method of producing the steel wire comprises the step of applying a residual compression stress on its surface, preferably by rolling in a rolling machine (3).

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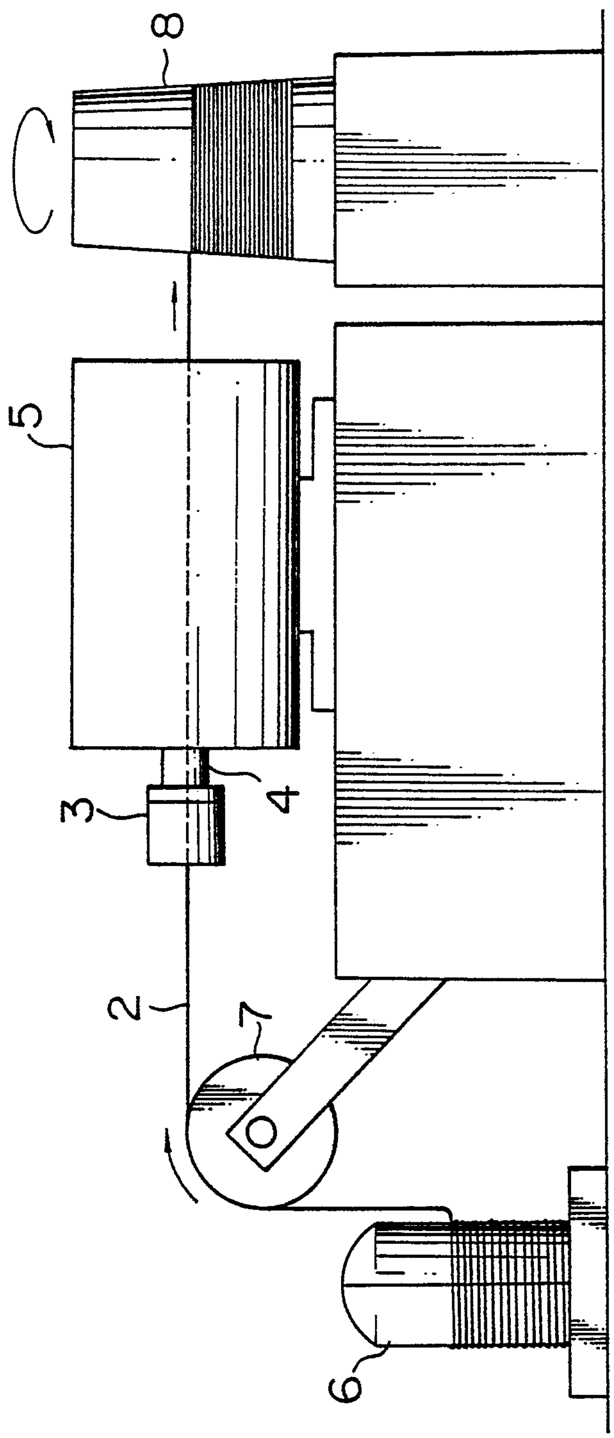
FIG. 1



HIGH TENSILE STRENGTH DRAWN STEEL WIRE WITH IMPROVED DUCTILITY

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a high tensile strength steel wire having excellent ductility.

DESCRIPTION OF THE PRIOR ART

In hard drawn steel wires manufactured which are used as steel wire for ropes, as tire reinforcing steel wire, as optical fiber cable reinforcing steel wire or as steel wire for suspension bridges, it is increasingly needed to strengthen wires.

Studies to increase the strength of hard drawn steel wires have been conducted energetically, but their strength has not yet reached an adequate level. This is caused by that increases in strength deteriorates the ductility and the technology for prevention of this deterioration has not yet been established. The torsional characteristics of steel wires, which is regarded as the criteria for ductility, can be improved by bluing drawn steel wires at a high temperature, as described on Page 50 of Wire Journal vol. 16, No. 4 (1983). Such a high temperature processing, however, leads to a decrease in the strength of a wire. In addition, it oxidizes the surface of small-gage wire used as tire reinforcing steel wire and thereby diminishes its ductility. Thus, its application has been limited.

Apart from this heat processing, an attempt has been made to increase ductility by releasing residual tensile stress present on the surface of a drawn steel wire by skin pass drawing of the drawn steel wire. However, this process is not capable of improving the ductility, as described in the paper titled "Effect of Dies Schedule on Mechanical Properties and Residual Stress of Steel Wire" which was submitted to the Drawing Technology Subcommittee of Japan Society for Plastic Processing.

It has been known to impart residual compression stress to the surface of a steel wire for the purpose of increasing fatigue properties. However, there is no apparent relationship between the fatigue properties and ductility, as is described on Page 392 of "Strength and Fracture of Iron and Steel Materials (1964)". This means that it is not possible to derive the method to improve the ductility from that of fatigue property.

Thus, known methods of increasing ductility of steel wires have all proved inadequate.

SUMMARY OF THE INVENTION

Accordingly, an objective of the present invention is to provide a steel wire which has excellent ductility.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an illustration of a typical method of surface machining a steel wire by rolling;

Fig. 2 illustrates a typical rolling instrument in detail;

Figs. 3A, 3B, 4A and 4B are side and front views of rollers;

Fig. 5 is an illustration of a typical method of surface machining a steel wire by shot peening;

Figs. 6 and 7 are typical illustrations of normal and abnormal ways by which a steel wire-breaks in a torsion test, respectively; and

Fig. 8 shows a longitudinal crack appeared on a wire surface in a torsion test.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described hereinunder in detail.

A steel wire of the present invention contains the following chemical components in amounts described below for the reasons described below.

It contains 0.4 to 1.0% C, because, if the content thereof were less than 0.4%, the required strength is not attained, and with over 1.0% C, the ductility of the resulting steel wire is greatly decreased.

Si is added because it is capable of setting a solid solution hardening, and the amount employed is limited to 2.0% or less, since the ductility becomes decreased when over 2% is contained in a steel wire.

Mn is contained to assure hardenability and fix S as MnS, and the amount thereof is set at between 0.2 and 2.0%, since less than 0.2% Mn is not capable of sufficiently fixing S and the hardenability thereof does not increase with a content of over 2% Mn.

The less P and S the steel wire contains, the better its quality in terms of improved ductility. Ductility is deteriorated conspicuously with over 0.02% of either, and the amount thereof is therefore limited to 0.02% or less.

N is contained in an amount of 0.01% or less, since with a content of over 0.01% thereof a deterioration in the ductility is apparent.

The thus-composed steel wire of the present invention contains, in addition to the ingredients described above, at least one ingredient selected from group (A) consisting of 0.05 to 3% of Cr, 0.01 to 1% of Mo, 0.01 to 1% of W, 0.05 to 3% of Cu, 0.1 to 5% of Ni and 0.1 to 5% of Co, and/or at least one ingredient selected from group (B) consisting of 0.001 to 0.1% of Al, 0.001 to 0.1% of Ti, 0.001 to 0.1% of Nb, 0.001 to 0.1% of V, 0.0003 to 0.05% of B, 0.001 to 0.1% of Mg and 0.001 to 0.1% of Ca.

Cr, Mo, W, Cu, Ni and Co are incorporated for the purpose of increasing the stength and corrosion resistance. They are not effective if added in amounts of less than 0.05%, 0.01%, 0.01%, 0.05%, 0.1% and 0.1%, respectively. The lower limit of the specified amounts thereof are therefore set at 0.05%, 0.01%, 0.01%, 0.05%, 0.1% and 0.1%, respectively.

Cr, Mo, W, Cu, Ni and Co are incorporated in amounts which are less than or equal to 3%, 1%, 1%, 3%, 5% and 5%, respectively. This is because when the content exceeds these amounts, the ductility of the steel wire is lowered, while the increase in strength and corrosion resistance is saturated. It is preferable for the total amount of these elements to be set at 7% or less from the viewpoint of good ductility.

Al, Ti, Nb, V, B, Mg and Ca are added in the steel wire for the purpose of increasing the ductility thereof by fixing N and S. Their effects are not apparent, however, if added in amounts which are less than 0.001%, 0.001%, 0.001%, 0.001%, 0.0003%, 0.001% and 0.001%, respectively. The amounts thereof are therefore set to be at least 0.001%, 0.001%, 0.001%, 0.0003%, 0,001% and 0.001%, respectively.

If, on the other hand, Al, Ti, Nb, V, B, Mg and Ca are added in amounts which are over 0.1%, 0.1%, 0.1%, 0.1%, 0.05%, 0.1% and 0.1%, respectively, the ductility of the steel wire is decreased due to the resulting nitride and sulfide of these elements, while their respective effects are saturated. The amounts thereof to be added are therefore set to be no more than 0.1%, 0.1%, 0.1%, 0.1%, 0.05%, 0.1% and 0.1%, respectively. The total amount of these elements is preferably set at 0.2% at most to ensure the quality in terms of ductility.

The steel wire of the present invention has a strength of at least 130 kgf/mm², since, if the strength is less than 130 kgf/mm², the ductility does not increase even if there is a residual compression stress on the surface of the steel wire.

The steel wire according to the present invention has a residual compression stress of between -(0.05 σ + 23) and (0.35 σ + 28) kgf/mm² on the surface thereof, depending on its strength σ, for the reasons described below.

The ductility of steel wire is generally determined by tensile, torsion and bending tests, based on such results as the elongation and reduction of area observed in the tensile test, and the number of turns (torsion number) to fracture and the mode of that fracture ovserved in the torsion test.

Of all these measures of ductility, the mode of fracture in torsion test is deteriorated mostly when the strength of steel wire is increased.

Figs. 6 and 7 illustrate typical ways in which a steel wire 2 fractures in torsion tests. Fig. 6 shows a normal mode of fracture in steel wire, while Fig. 7 illustrates an abnormal fracture with cracks 11. The abnormal type of fracutre occurs more frequently as the strength of the steel wire 2 increases. It is caused by the occurence of a longitudinal crack 11 as shown in Fig. 8, in which a wire is twisted by chuching with jig 12. It can therefore be considered that abnormal fracture means a deterioration in the ductility in the circumferential direction of the steel wire.

The fact that an increase in the strength of steel wire decreases the ductility in the circumferential direction is most clearly related to the phenomena whereby the steel wire cracks often in the longitudinal direction during bending, before failure occurs, and whereby longitudinal cracks is occured frequently during the bunching of the steel wire, before failure occurs. It is understood from the foregoing description that the manner in which fracture occurs in a torsion test is the most important criterion of the ductility of steel wire.

The present inventors have found that the ductility of steel wire in the cricumferential direction can be effectively increased by providing its surface with a residual compression stress, and they have studied the appropriate range for the application of this residual compression stress. More specifically, the present inventors set themselves the goal of reducing the incidence of abnormal fracture to 10% or less in torsion tests, and investigated how the level of the surface residual compression stress and the occurrence of abnormal fracture are related, using steel wire having tensile strengths of 152 kgf/mm², 235 kgf/mm², 316 kgf/mm² and 377 kgf/mm², respectively.

From the results obtained, it was concluded that it is essential for steel wires having tensile strengths of 152 kgf/mm², 235 kgf/mm², 316 kgf/mm² and 377 kgf/mm² to possess a residual compression stress of at least 29 kgf/mm², 36 kgf/mm², 38 kgf/mm² and 42 kgf/mm², respectively, so as to decrease the incidence of abnormal fracture to 10% or less, on the basis of torsion tests which were conducted. Each of these residual compression stresses, when observed relative to the corresponding tensile strength σ, was found experimentally to be equal to $(0.05\ \sigma + 23)$ kgf/mm^2. If the incidence of abnormal fracture is reduced to 10% or less in such torsion tests, there is no problem related to the occurrence of longitudinal cracks during the practical processing of the steel wire. Thus, the lower limit of the residual compression stress to be applied to the surface of steel wire was set at $(0.05\ \sigma + 23)$ kgf/mm^2. This value of course changes as its strength increases.

The higher the residual compression stress applied to the surface of the steel wire, the better its ductility in the circumferential direction. However, the residual tensile stress at the center of the steel wire increases in proportion to the residual compression stress on the surface, as is generally known, and cracks are thereby occured in the center which lead to abnormal fracture in torsion tests. This determines the maximum allowable residual compression stress which can be applied to the surface. The present inventors have investigated how the occurrence of abnormal fracture due to cracks generated in the center of the steel wire is related to the level of residual compression stress which is applied, using four types of steel wires of the same strengths as those employed before.

From the results of these investigations, it was concluded that abnormal fractures begin to occur in steel wires which have tensile strengths of 152 kgf/mm^2, 235 kgf/mm^2, 316 kgf/mm^2 and 377 kgf/mm^2, respectively, when the residual compression stresses applied to the surfaces exceed 80 kgf/mm^2, 113 kgf/mm^2, 136 kgf/mm^2 and 160 kgf/mm^2, respectively. These residual compression stresses are proportional to the corresponding wire strengths σ, and were found experimentally to be equal to $(0.35\ \sigma + 28)$ kgf/mm^2. The upper limit of the residual compression stress to be applied was thus determined to be $(0.35\ \sigma + 28)$ kgf/mm^2.

Subsequently, the present inventors made a quantitative study to clear the appropriate range of application of strain by means of surface machining which is required to maintain the surface residual compression stress in the above-described range, and found that the strain should be limited to between 0.2 and 10% to do so. This is because, if the strain is less than 0.2%, residual compression stress within the above-described range cannot be applied on the surface. On the other hand, fine cracks are appeared on the surface of a steel wire and the ductility thereof tends to decrease when the strain exceeds 10%. Thus, the range of strain application by surface machining is restricted to between 0.2 and 10%.

The residual compression stress of the above-described range is practically applied to the surface of a steel wire by surface machining it such as to impart a strain of between 0.2 and 10% in the following manner.

Fig. 1 illustrates a typical method of applying surface residual compression stress by rolling. In the Figure, the steel wire 2 is unwound from a unwinding machine 6, is passed through a pinch roller 7, and is wound on a winding machine 8. The pinch roller 7 is adapted to supply a tension to the steel wire 2. The steel wire 2 is surface machined by a rolling machine 3 located between the pinch roller and the wind machine 8.

Fig. 2 shows the rolling jig 3 in detail. Strain is applied to the surface of the steel wire 2 by passing it between a plurality of spherical rollers 1 which are rotated by being rubbed against the passing steel wire. The amount of strain to be applied may be controlled by adjusting the rolling reduction of the rollers 1.

Rollers of a disk-shaped configuration as shown in Figs. 3A, 3B and 4A, 4B may also be employed. In such a case, it is necessary for the end of the rollers 20 and 21 to have a flat or convex shape. This is because the experiments confirmed that if the configuration thereof is concave, it is impossible to apply a surface residual compression stress at a level in the above-described range.

The rolling machine jig 3 may include more than one pair of rollers. This may be a more effective way of carrying out the present invention than employing just one pair of rollers.

The present invention may be carried out more effectively by transmitting the rotation of a motor 5 to the rolling machine 3 through a shaft 4 and rotating the rolling machine 3 about the steel wire 2. At this time, if the rollers employed are of a disk-like shape, the rollers are disposed at a certain angle relative to the steel wire 2.

Fig. 5 illustrates a typical method of applying a residual compression stress to the surface by shot peening a steel wire. A shot 9 may be blasted through a pipe 10 by means of compressed air or by rotating the jig 3 about the steel wire so as to surface machine the steel wire.

This surface machining may be conducted immediately after the steel wire comes out of the dies in the wire drawing process or at any time before completion of the final product. If the steel wire is surface machined after blueing or plating, however, it is preferable for the steel wire to be blued again at a temperature of 250°C or less so as to improve the stress relaxation.

At this time, it is preferable for the difference in hardness between the core and surface of the steel wire to be set at 100 or less in vickers hardness. This is because if it exceeds 100, the steel wire may crack during rolling.

A steel wire of the present invention exhibits excellent characteristics in terms of fatigue, corrosion fatigue, delayed fracture, stress corrosion cracking or relaxation properties.

When employed in such products as ropes, steel wire reinforced tires and steel wire reinforced plastics, the steel wire of the present invention is capable of improving the durability or fatigue characteristics of these products.

The present invention will be described hereinunder by way of examples.

Table 1 lists the compositions, diameters, tensile strengths of the steel wires employed in the examples, the minimum values (0.05 σ + 23) and the maximum values (0.35 σ + 28) of residual compression stresses which can be applied to the surfaces of steel wires which are determined in accordance with the present invention, the residual stresses existing on the surfaces of the steel wires employed in the examples, the results of tests for twisting, fatigue, corrosion fatigue, delayed fracture, and relaxation on these steel wires, and the results of a fatigue test conducted on products employing these steel wires.

The results of the tests listed in the table are expressed as follows.

The symbol + in the item for residual stress indicates that the residual stress is one of tension, while the symbol -means that the stress is one of compression.

Abnormal type fracture frequencies refer to occurrences of the abnormal type of fracture shown in Fig. 7 in the torsion tests conducted.

Fatigue limits indicate stresses at the fatigue limits observed in the rotary bending tests conducted.

Breakage ratios of cords in tires are those for cords employed in tires subjected to a load of 500 kg while running of 100,000 km.

Relaxation rates show the residual shear strains observed in steel wires 96 hours after being subjected to torsional stress equivalent to 60% of the maximum torsional strength.

Delayed fracture hours refer to the hours to fracture of steel wires when subjected to a tensile stress of 80 kgf/mm² in a solution of 0.1N hydrochloric acid.

Fatigue limits of plastic plates refer to the bending fatigue limits observed in plastic plates having a thickness of 1 mm and a width of 10 mm reinforced by 100 steel wires per 1 mm². These are expressed by the ratio of the measured value to that of No. 31 sample.

Corrosion fatigue lives represent the number of rotations to fracture of steel wires when subjected to a load of 20 kgf/mm² in rotary bending fatigue tests conducted in a 3% NaCl solution.

Stress corrosion cracking hours represent the hours to fracture of steel wires when subjected to a tensile strength of 70 kgf/mm² in a solution of 0.5% acetic acid + 5% NaCl.

Rope fatigue limits show the bending fatigue limits of ropes which conform to JIS No. 1. The rope made from the steel wire shown in example no. 47 of this invention was compared with one made from the steel wire of comparison example No. 48, and the fatigue limits of these ropes were expressed by the ratio of the measured value to that of No. 31 sample.

In Table 1, the test Nos. which are circled indicate examples of this invention. The others represent comparison examples.

Tests Nos. 1 and 2 use steel wires having diameters of 0.2 mm and the tensile strengths of 332 kgf/mm² and composed of the same chemical components. The steel wire of No. 1 had a residual compression stress of 112 kgf/mm² which was imparted by applying a strain of 1.2% by rolling, and showed an abnormal fracture ratio of 0 in the torsion test conducted. On the other hand, the steel wire of test No. 2 had a residual tensile stress of 61 kgf/mm², and showed an abnormal fracture rate of 100%. This shows that the steel wire of this invention is excellent in ductility. The steel wire of this invention also exhibited excellent characteristics in terms of corrosion fatigue properties as well as durability when employed in a tire.

Tests Nos. 3 and 4 employed steel wires respec-tively having diameters of 2.6 mm and 4.5 mm, tensile strengths of 168 kgf/mm² and 196 kgf/mm², and residual compression stresses of 50 kgf/mm² and 83 kgf/mm². Both showed an abnormal fracture ratio of 0, and were excellent in ductility. For both wires, the residual compression stresses were imparted by applying strains of 0.3% and 0.9%, respectively, by shot peening.

Tests Nos. 5, 6, 7 and 8 used steel wires having compositions and residual stresses outside the scope of the present invention. Hence, these showed high rates of abnormal fracture and poor ductility.

Nos. 9 and 10 represent the tests employing steel wires having diameters of 0.25 mm, tensile strengths of 286 kgf/mm², and the same composition. The steel wire of test No. 9 had a residual compression stress of 87 kgf/mm², and showed an abnormal fracture ratio of 5% in the torsion test conducted, while the steel wire of No. 10 had a residual tensile stress of 45 kgf/mm², and therefore showed an abnormal fracture ratio of 95%. From these tests, it is clear that the steel wire according to the present invention has excellent ductility. The residual compression stress was imparted to both steel wires by applying a strain of 6.2% by rolling.

Test No. 11 employed a steel wire having a diameter of 2.5 mm, a tensile strength of 205 kgf/mm² and a residual compression stress of 60 kgf/mm². The steel wire showed an abnormal fracture ratio of 0, which shows that the ductility thereof was excellent. The residual compression stress was imparted by applying a strain of 1.0% by shot peening.

Tests Nos. 12 and 13 represent examples of steel wires having diameters of 0.6 mm and tensile strengths of 256 kgf/mm² and which are composed of the same components. The steel wire of No. 12 had a residual compression stress of 65 kgf/mm², while that of No. 13 was 130 kgf/mm². The latter was imparted its residual compression stress by applying a rolling strain of 12%. The abnormal fracture ratio of No. 12 represented 5%, while that of No. 13 reached 70%. The steel wire of the present invention thus proved to be excellent in ductility. The residual compression stress was imparted to the steel wire of example No. 12 by applying a strain of 0.3% through rolling.

Tests Nos. 14 and 15 employed a steel wire and a galvanized steel wire, respectively, which had diameters of 4.5 mm and 3.2 mm, tensile strengths of 195 kgf/mm² and 1790 kgf/mm² and residual compression stresses of 45 kgf/mm² and 41 kgf/mm², respectively. Both wires showed abnormal fracture ratio of 0, and proved to be excellent in ductility. The residual compression stresses were imparted to the steel wires of Nos. 14 and 15 by applying a strain of 2.0% through rolling and a strain of 0.5% through shot peening, respectively.

Tests Nos. 16 to 18 concern the steel wires having diameters of 8 mm and tensile strengths of 152 kgf/mm² which were composed of the same components. The steel wire of No. 16 had a residual compression stress of 41 kgf/mm², and showed an abnormal fracture ratio of 5%. Nos. 17 and 18 had a residual tensile stress of 25 kg/mm² and a residual compression stress of 18 kgf/mm², respectively, and their abnormal fracture ratios respectively represented 60% and 45%. The steel wires of the present invention thus proved to have excellent ductility. The residual compression stresses were imparted to the steel wires of Nos. 16 and 18 by applying strains of 0.3% through shot peening and 0.8% through rolling, respectively. The steel wire of the present invention also exhibited excellent characteristics in relaxation and delayed fracture properties.

Tests Nos. 19 and 20 employed steel wires respectively having diameters of 1.2 mm and 3.6 mm, tensile strengths of 220 kgf/mm² and 184 kgf/mm² and residual compression stresses of 78 kgf/mm² and 50 kgf/mm². Both exhibited abnormal fracture ratios of 5% and 0%, respectively, and proved to be excellent in ductility. The residual compression stresses were imparted to both wires by applying strains of 0.5% and 3.2%, respectively, through rolling.

Nos. 21 to 27 represent comparison examples employing steel wires whose compositions and residual stresses are outside the scope of the present invention. Hence, both showed high abnormal fracture ratios and poor ductility.

Tests Nos. 28 and 29 used steel wires respectively having diameters of 2.0 mm and 0.8 mm, tensile strengths of 196 kgf/mm² and 258 kgf/mm², and residual compression stresses of 60 kgf/mm² and 72 kgf/mm². Abnormal fracture ratios for both wires showed 0 and 5%, respectively, and their ductilities proved to be excellent.

Tests Nos. 30 and 31 employed steel wires having diameters of 0.06 mm and tensile strengths of 408 kgf/mm² which were composed of the same components. The steel wire of No. 30 had a residual compression stress of 76 kgf/mm², and showed an abnormal fracture ratio of 5%, while the steel wire of No. 31 had a residual tensile strength of 50 kgf/mm² and the abnormal fracture ratio thereof therefore represented 100%. Ductility of the steel wire in accordance with the present invention thus proved to be excellent. It also proved that the plastic plate reinforced by the steel wire according to the present invention had excellent fatigue property. The residual compression stress was imparted by applying a strain of 0.2% through rolling.

Test No. 32 concerns a steel wire having a diameter of 5.5 mm, a tensile strength of 185 kgf/mm² and a residual compression stress of 65 kgf/mm². The employed wire showed an abnormal fracture ratios of 0, and proved to be excellent in ductility.

Tests Nos. 33 and 34 represent examples employing steel wires having diameters of 3.2 mm and tensile strengths of 146 kgf/mm² which were composed of the same ingredients. The steel wrie of No. 33 had a residual compression stress of 45 kgf/mm², and showed an abnormal fracture ratio of 0. The steel wire of No. 34 had a residual compression stress as high as 93 kgf/mm² which was imparted thereto by applying a rolling strain of 15%, and hence showed an abnormal fracture ratio of 35%. This shows that the steel wire of the present invention was excellent in ductility.

Tests Nos. 35 and 36 used steel wires respectively having diameters of 3.2 mm and 0.3 mm, tensile strengths of 170 kgf/mm² and 238 kgf/mm² and residual compression stresses of 50 kgf/mm² and 69 kgf/mm². Abnormal fracture ratios for both steel wires represented 0 and 5%, respectively, and both proved to have excellent ductility. Residual compression stresses were imparted to the steel wires of Nos. 32, 33, 35 and 36 by applying strains of 0.8%, 0.2%, 2.0% and 1.2% through shot peening, respectively.

Tests Nos. 37 to 42 represent comparison examples employing steel wires having compositions and residual stresses outside the scope of the present invention. The abnormal fracture ratios of these steel wires were therefore high, and their ductilities were poor. An excessively high residual compression stress was imparted to the steel wire of No. 40 by applying a strain as high as 10.8% through rolling.

Tests Nos. 43 to 46 employed steel wires respectively having diameters of 2.0 mm, 3.6 mm, 1.2 mm and 0.35 mm, tensile strengths of 195 kgf/mm², 185 kgf/mm², 221 kgf/mm² and 260 kgf/mm², and residual compression stresses of 75 kgf/mm², 50 kgf/mm², 40 kgf/mm² and 80 kgf/mm². In all cases, the abnormal fracutre ratios represented 0, and the ductilities proved to be excellent.

Tests Nos. 47 and 48 used steel wires having diameters of 3.6 mm tensile strengths of 228 kgf/mm² and the same compositions. The steel wire of No. 47 had a residual compression stress of 63 kgf/mm², showed an abnormal fracture ratio of 0 and proved to be excellent in ductility. The steel wire of No. 48, on the other hand, had a residual tensile stress of 30 kgf/mm², and the abnormal fracture ratio thereof represented 75%. This shows that its ductility was poor.

The steel wire of No. 47 proved also to be excellent in stress corrosion cracking property. The rope made of this steel wire showed excellent characteristics in fatigue properties.

The residual compression stresses were imparted to the steel wires of Nos. 43, 44, 45, 46 and 47 by applying rolling strains of 3.0%, 0.6%, 7.8%, 1.0% and 1.5%, respectively.

Tests Nos. 49 and 50 employed steel wires having diameters of 0.6 mm, tensile strengths of 290 kgf/mm² and the smae compositions. The steel wire of No. 49 had a residual compression stress of 86 kgf/mm², and showed an abnormal fracture ratio of 0, which represents excellent ductility. On the other hand, a residual tensile stress as high as 43 kgf/mm² was imparted to the steel wire of No. 50, and the abnormal fracture ratio thereof rose as high as 90%. It is clear that the steel wire of No. 50 had poor ductility. The steel wire of No. 49 also exhibited excellent characteristics in fatigue properties. The residual compression stress was imparted to the wire of No. 49 by applying a strain of 0.7% through shot peening.

Tests Nos. 51 to 55 represent comparison examples employing steel wires having compositions and residual stresses outside the scope of the present invention. The abnormal fracture ratios of these steel wires were therefore high with poor ductility. The steel wire of No. 54 was subjected to a strain as high as 11.6% by rolling, and had a large residual compression stress.

The difference in the hardnesses of the core and the surface of each steel wire according to the present invention represented a Vickers hardness of less than 100. The hardness difference in the case of the steel wires belonging to comparison examples Nos. 5, 26, 38 and 54, however, exceeded 100.

Table 1

Test No.	Components (weight %)							
	C	Si	Mn	P	S	N	Cr	Mo
①	0.70	0.12	0.55	0.008	0.005	0.0030	-	-
2	"	"	"	"	"	"	-	-
③	0.51	1.20	0.96	0.013	0.002	0.0048	-	-
④	0.82	0.21	0.76	0.010	0.008	0.0055	-	-
5	1.12	0.75	1.20	0.016	0.012	0.0113	-	-
6	0.36	2.15	0.50	0.011	0.008	0.0070	-	-
7	0.65	0.35	0.96	0.032	0.016	0.0042	-	-
8	0.90	0.25	0.13	0.009	0.028	0.0056	-	-
⑨	0.72	0.30	0.45	0.008	0.002	0.0033	0.96	-
10	"	"	"	"	"	"	"	-
⑪	0.60	1.32	1.20	0.010	0.005	0.0070	-	-
⑫	0.86	0.25	0.55	0.005	0.002	0.0052	-	-
13	"	"	"	"	"	"	-	-
⑭	0.65	0.70	0.83	0.012	0.008	0.0035	0.45	-
⑮	0.45	0.15	0.35	0.006	0.004	0.0043	-	0.13
⑯	0.55	1.2	0.9	0.015	0.009	0.0081	0.3	-
17	"	"	"	"	"	"	"	-
18	"	"	"	"	"	"	"	-
⑲	0.78	0.40	0.81	0.013	0.011	0.0040	-	-

- Cont'd -

Table 1 (Cont'd)

Components (weight %)							
W	Cu	Ni	Co	Al	Ti	Nb	V
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
0.15	-	-	-	-	-	-	-
-	-	-	2.5	-	-	-	-
-	-	-	"	-	-	-	-
-	1.2	-	-	-	-	-	-
-	-	2.5	-	-	-	-	-
-	1.2	-	2.2	-	-	-	-
-	"	-	"	-	-	-	-
-	"	-	"	-	-	-	-
0.2	-	1.3	0.6	-	-	-	-

- Cont'd -

Table 1 (Cont'd)

Components (weight %)			Diameter (mm)	Tensile strength σ (kgf/mm^2)
B	Mg	Ca		
-	-	-	0.2	332
-	-	-	"	"
-	-	-	2.6	168
-	-	-	4.5	196
-	-	-	6.5	150
-	-	-	3.2	135
-	-	-	1.6	206
-	-	-	2.0	212
-	-	-	0.25	286
-	-	-	"	"
-	-	-	2.5	205
-	-	-	0.6	256
-	-	-	"	"
-	-	-	4.5	195
-	-	-	3.2	170
-	-	-	8	152
-	-	-	"	"
-	-	-	"	"
-	-	-	1.2	220

- Cont'd -

Table 1 (Cont'd)

Compressive residual stress 0.05σ + 23 (kgf/mm2)	Compressive residual stress 0.35σ + 28 (kgf/mm2)	Residual stress (kgf/mm2)
-40	-144	-112
"	"	+61
-31	-87	-50
-33	-97	-83
-31	-81	+38
-30	-75	-15
-33	-100	-65
-34	-102	-53
-37	-128	-87
"	"	+45
-33	-100	-60
-36	-118	-65
"	"	-130
-33	-97	-45
-32	-88	-41
-31	-81	-41
"	"	+25
"	"	-18
-34	-105	-78

- Cont'd -

Table 1 (Cont'd)

Abnormal fracture rate (%)	Other characteristics
0	Corrosion fatigue 4 x 10^7 Breakage rate of cord in tire 0%
100	Corrosion fatigure 8 x 10^5 Breakage rate of cord in tire 8%
0	
0	
70	
45	
35	
50	
5	
95	
0	
5	
70	
0	
0	
5	Relaxation rate 4 x 10^{-3} There is no break in delayed fracture time 10,000 minites
60	Relaxation rate 2 x 10^{-2} Delayed fracture time 700 minites
45	
5	

Table 1 (Cont'd)

Test No.	Components (weight %)							
	C	Si	Mn	P	S	N	Cr	Mo
20	0.55	0.25	0.63	0.009	0.006	0.0039	0.20	0.05
21	0.72	0.31	0.81	0.016	0.012	0.012	3.4	-
22	0.92	0.45	1.20	0.009	0.003	0.0073	-	1.3
23	0.37	0.80	0.66	0.018	0.005	0.0120	-	-
24	0.56	0.20	0.80	0.026	0.003	0.0045	-	-
25	0.68	1.46	1.02	0.013	0.015	0.0081	3.5	-
26	0.50	0.62	0.45	0.013	0.036	0.0055	0.003	-
27	0.84	0.95	0.74	0.015	0.010	0.0039	-	0.003
28	0.62	1.30	1.20	0.010	0.006	0.0055	-	-
29	0.82	0.24	0.73	0.009	0.004	0.0036	-	-
30	0.65	0.22	0.39	0.005	0.002	0.0020	-	-
31	"	"	"	"	"	"	-	-
32	0.77	0.35	0.50	0.014	0.003	0.0062	-	-
33	0.45	0.20	0.82	0.008	0.005	0.0041	-	-
34	"	"	"	"	"	"	-	-
35	0.73	0.30	1.60	0.007	0.001	0.0036	-	-
36	0.56	1.02	0.75	0.012	0.008	0.0080	-	-
37	0.36	0.50	1.33	0.006	0.002	0.0126	-	-
38	0.78	0.26	0.75	0.011	0.011	0.0060	-	-

- Cont'd -

Table 1 (Cont'd)

Components (weight %)							
W	Cu	Ni	Co	Al	Ti	Nb	V
-	0.8	0.46	1.9	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
1.2	-	-	-	-	-	-	-
-	-	-	5.9	-	-	-	-
-	0.02	5.5	-	-	-	-	-
-	3.5	0.06	-	-	-	-	-
1.6	-	-	0.04	-	-	-	-
-	-	-	-	0.022	-	-	-
-	-	-	-	-	0.010	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	0.025	-	0.016	-
-	-	-	-	-	0.023	-	-
-	-	-	-	-	"	-	-
-	-	-	-	-	-	0.010	0.021
-	-	-	-	0.038	0.010	-	-
-	-	-	-	0.13	-	-	-
-	-	-	-	-	0.14	-	-

- Cont'd -

Table 1 (Cont'd)

Components (weight %)			Diameter (mm)	Tensile strength σ (kgf/mm^2)
B	Mg	Ca		
-	-	-	3.6	184
-	-	-	4.0	196
-	-	-	0.8	240
-	-	-	2.0	145
-	-	-	4.2	160
-	-	-	1.6	216
-	-	-	1.2	153
-	-	-	0.3	330
-	-	-	2.0	196
-	-	0.006	0.8	258
-	0.005	-	0.06	408
-	"	-	"	"
-	-	-	5.5	185
0.002	-	-	3.2	146
"	-	-	"	"
-	0.010	-	"	170
0.0009	0.003	-	0.3	238
-	-	-	3.6	143
-	-	0.13	0.6	260

- Cont'd -

Table 1 (Cont'd)

Compressive residual stress $0.05\sigma + 23$ (kgf/mm^2)	Compressive residual stress $0.35\sigma + 28$ (kgf/mm2)	Residual stress (kgf/mm^2)
-32	-83	-50
-33	-97	-41
-35	-112	-55
-30	-79	-20
-31	-84	-60
-34	-104	-55
-31	-82	+35
-40	-144	-95
-33	-97	-60
-36	-118	-72
-43	-171	-76
"	"	+50
-32	-93	-65
-30	-79	-45
"	"	-93
-32	-88	-50
-35	-112	-69
-30	-79	-42
-36	-118	+40

- Cont'd -

Table 1 (Cont'd)

Abnormal fracture rate (%)	Other characteristics
0	
70	
90	
40	
45	
60	
40	
95	
0	
5	
5	Fatigue limit of plastic plate 1.4
100	Fatigue limit of plastic plate 1
0	
0	
35	
0	
5	
40	
70	

Table 1 (Cont'd)

Test No.	Components (weight %)							
	C	Si	Mn	P	S	N	Cr	Mo
39	0.55	2.21	0.45	0.010	0.003	0.0046	-	-
40	0.62	0.70	0.15	0.016	0.010	0.0060	-	-
41	0.84	0.06	2.30	0.029	0.006	0.0033	-	-
42	1.10	0.27	0.65	0.008	0.032	0.0041	-	-
(43)	0.70	0.30	0.45	0.006	0.006	0.0065	1.2	-
(44)	0.88	0.15	0.45	0.003	0.001	0.0030	-	-
(45)	0.55	0.25	0.50	0.013	0.007	0.0040	2.0	-
(46)	0.72	0.12	0.55	0.006	0.003	0.0029	-	-
(47)	0.83	0.93	1.3	0.009	0.003	0.0045	2.0	-
48	"	"	"	"	"	"	"	-
(49)	0.88	0.12	0.49	0.016	0.006	0.0032	-	0.1
50	"	"	"	"	"	"	-	"
51	0.46	0.26	0.40	0.011	0.006	0.0088	3.3	-
52	0.42	0.30	0.51	0.006	0.029	0.0035	-	1.2
53	0.72	2.3	0.76	0.009	0.011	0.0090	0.02	-
54	0.52	0.60	2.30	0.016	0.009	0.0070	-	0.006
55	1.10	0.45	1.15	0.026	0.010	0.013	-	-

- Cont'd -

Table 1 (Cont'd)

Components (weight %)							
W	Cu	Ni	Co	Al	Ti	Nb	V
-	-	-	-	-	-	-	-
-	-	-	-	0.03	-	0.012	-
-	-	-	-	-	0.0006	-	0.13
-	-	-	-	0.0004	-	0.0006	-
-	-	-	-	0.030	-	-	-
-	2.0	-	-	-	0.019	-	-
-	-	-	3.5	-	-	-	-
-	-	3.5	-	-	-	-	0.010
0.3	-	-	-	0.08	-	0.02	0.05
"	-	-	-	"	-	"	"
-	-	3.6	-	-	0.012	-	-
-	-	"	-	-	"	-	-
-	-	0.6	-	-	0.12	-	-
-	1.3	-	-	-	-	0.14	-
1.2	-	0.06	0.03	0.13	-	0.013	-
0.008	-	-	5.7	-	-	-	0.004
-	3.2	5.3	-	0.026	0.0007	-	0.15

- Cont'd -

Table 1 (Cont'd)

Components (weight %)			Diameter (mm)	Tensile strength σ (kgf/mm²)
B	Mg	Ca		
0.07	-	-	4.0	161
-	-	-	2.0	194
-	0.13	-	2.6	186
-	0.0007	-	4.8	196
-	-	-	2.0	195
-	-	0.012	3.6	185
-	0.005	-	1.2	221
0.002	-	-	0.35	260
-	-	-	3.6	228
-	-	-	"	"
0.001	0.003	-	0.6	290
-	-	-	"	"
-	-	-	2.6	169
-	-	-	1.2	153
-	-	-	7.2	160
0.07	0.12	-	2.0	170
-	0.0006	-	6.5	184

- Cont'd -

Table 1 (Cont'd)

Compressive residual stress $0.05\sigma + 23$ (kgf/mm2)	Compressive residual stress $0.35\sigma + 28$ (kgf/mm2)	Residual stress (kgf/mm^2)
-31	-84	-23
-33	-97	-108
-32	-93	-76
-33	-97	-50
-33	-97	-75
-32	-83	-50
-34	-105	-40
-36	-118	-80
-34	-108	-63
"	"	+30
-38	-130	-86
"	"	+43
-31	-87	-40
-31	-82	-16
-31	-84	-35
-32	-88	-106
-32	-93	-60

- Cont'd -

Table 1 (Cont'd)

Abnormal fracture rate (%)	Other characteristics	
55		
50		
85		
100		
0		
0		
0		
0		
0	Ratio of fatigu limit of rope 1.7	Hours to fracture in stress corrosion cracking test 700 hours
75	Ratio of fatigue limit of rope 1	Hours to fracture in stress corrosion cracking test 150 hours
0	Fatigue limit of 87 kgf/mm2	
90	Fatigue limit of 53 kgf/mm2	
40		
70		
65		
55		
100		

Claims

1. A high tensile strength drawn steel wire having excellent ductility, comprising a steel containing 0.4 to 1.0% by weight of C, 2.0% or less by weight of Si, 0.2 to 2% by weight of Mn, 0.02% or less by weight of P, 0.02% or less by weight of S and 0.01% or less by weight of N, wherein said steel has a strength σ of 130 kgf/mm² or more and a residual compression stress of between (0.05 σ + 23) and (0.35 σ + 28) kgf/mm² on the surface thereof, depending on its strength σ.

2. A high tensile drawn steel wire of claim 1 further containing: at least one ingredient selected from the group consisting of 0.05 to 3% by weight of Cr, 0.01 to 1% by weight of Mo, 0.01 to 1% by weight of W, 0.05 to 3% by weight of Cu, 0.1 to 5% by weight of Ni and 0.1 to 5% by weight of Co, and/or at least one ingredient selected from the group consisting of 0.001 to 0.1% by weight of Al, 0.001 to 0.1% by weight of Ti, 0.001 to 0.1% by weight of Nb, 0.001 to 0.1% by weight of V, 0.0003 to 0.05% by weight of B, 0.001 to 0.1% by weight of Mg, and 0.001 to 0.1% by weight of Ca.

3. A high tensile drawn steel wire having excellent ductility, comprising a steel containing 0.4 to 1.0% by weight of C, 2.0% or less by weight of

Si, 0.2 to 2% by weight of Mn, 0.02% or less by weight of P, 0.02% or less by weight of S and 0.01% or less by weight of N, said steel being hot rolled and this hot rolled or heat treated steel being drawn to prepare a steel wire having a strength σ of 130 kgf/mm^2 or more, said steel wire being surface machined so as to impart a strain of between 0.2 and 10% and thereby apply a residual compression stress of between $(0.05\ \sigma + 23)$ and $(0.35\ \sigma + 28)$ kgf/mm^2 on its surface, depending on the strength σ of said wire.

4. A high tensile drawn steel wire of claim 3 further containing: at least one ingredient selected from the group consisting of 0.05 to 3% by weight of Cr, 0.01 to 1% by weight of Mo, 0.01 to 1% by weight of W, 0.05 to 3% by weight of Cu, 0.1 to 5% by weight of Ni and 0.1 to 5% by weight of Co, and/or at least one ingredient selected from the group consisting of 0.001 to 0.1% by weight of Al, 0.001 to 0.1% by weight of Ti, 0.001 to 0.1% by weight of Nb, 0.001 to 0.1% by weight of V, 0.0003 to 0.05% by weight of B, 0.001 to 0.1% by weight of Mg, and 0.001 to 0.1% by weight of Ca.

5. A steel wire of any of claims 1, 2, 3 and 4, wherein said steel wire is surface machined by rolling with spherical rollers.

6. A steel wire of any of claims 1, 2, 3 and 4, wherein said steel wire is surface machined by rolling with disk-like shaped rollers.

7. A steel wire of any of claims 1, 2, 3 and 4, wherein said steel wire is surface machined by shot peening.

8. A method of producing a high tensile strength drawn steel wire having excellent ductility comprising the step of applying a residual compression stress on its surface.

FIG. 1

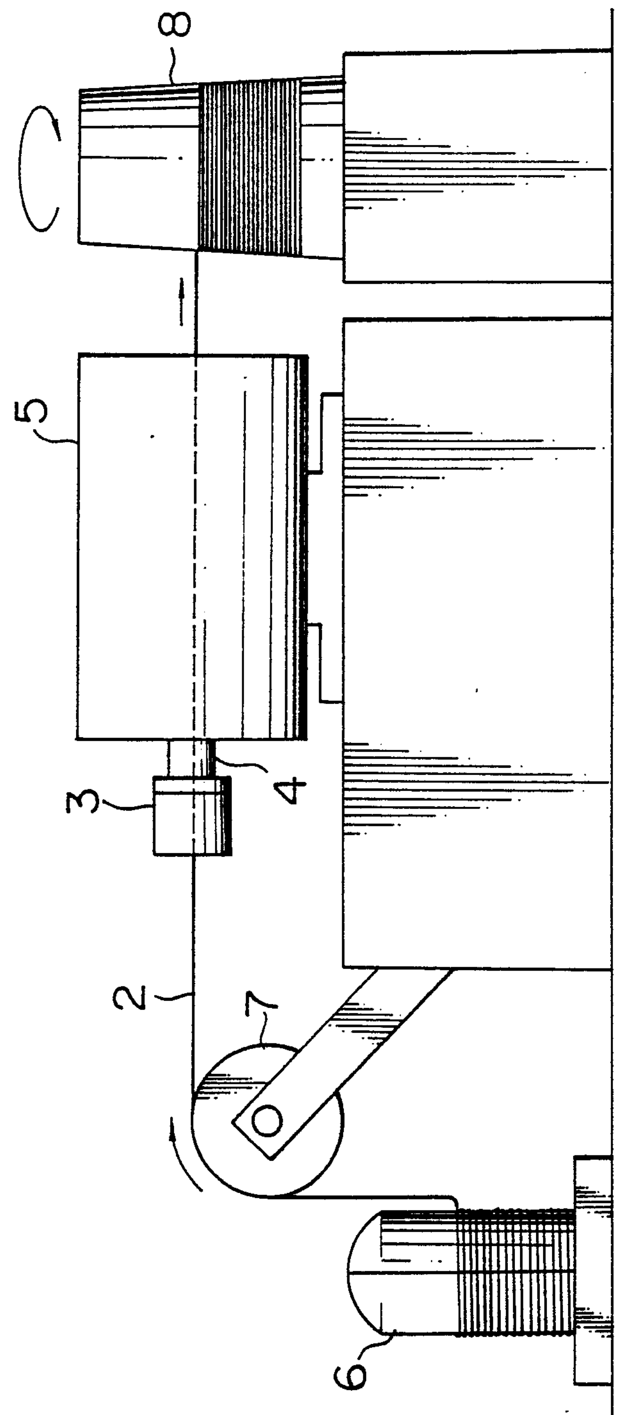


FIG. 2

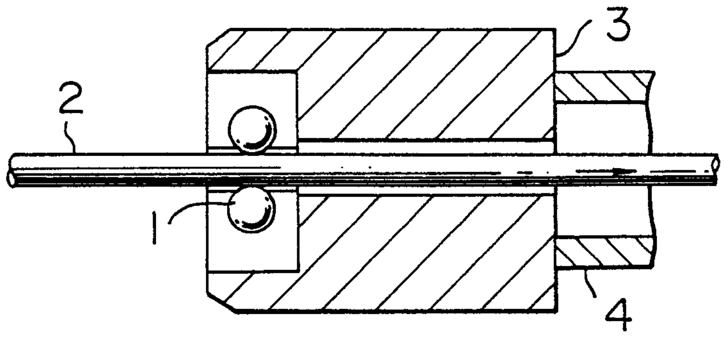


FIG. 3A

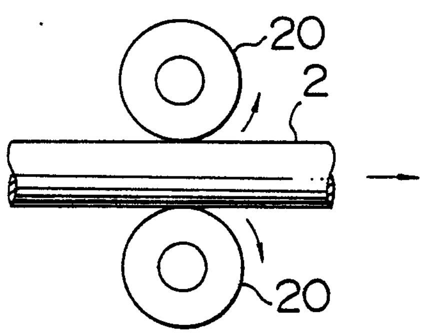


FIG. 3B

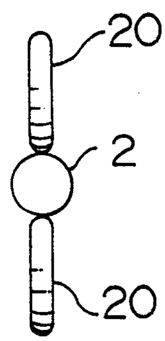


FIG. 4A

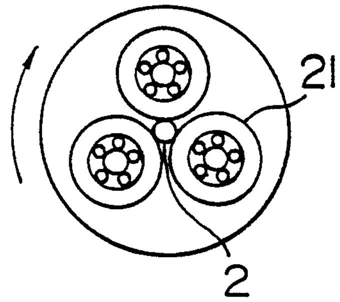


FIG. 4B

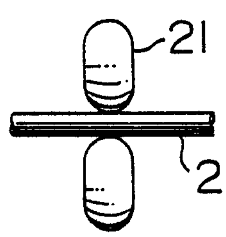


FIG. 5

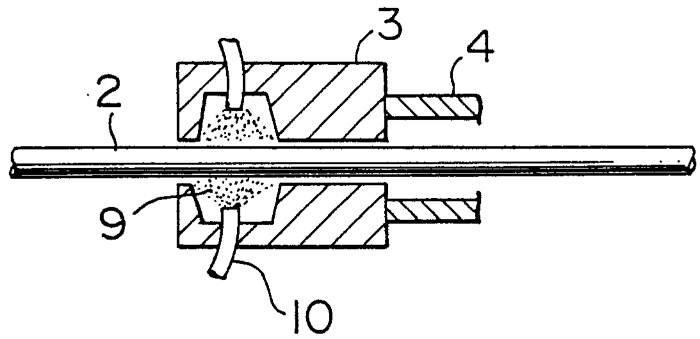


FIG. 6

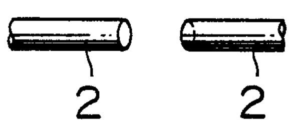


FIG. 7

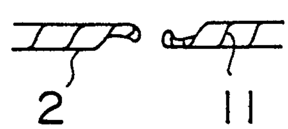
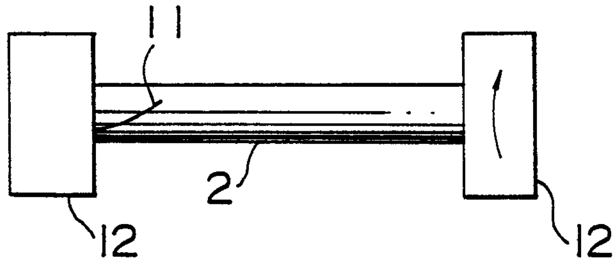


FIG. 8



European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86 11 3353

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	GB-A- 531 017 (RICHARD JOHNSON & NEPHEW) * Whole document *	1,7,8	C 21 D 7/04 C 21 D 8/06 // C 22 C 38/04
X	DE-C- 747 761 (O. FÖPPL) * Whole document *	1,5,6, 8	
X	PATENTS ABSTRACTS OF JAPAN, vol. 7, no. 61 (C-156)[1206], 15th March 1983; & JP-A-57 210 916 (SUMITOMO DENKI KOGYO K.K.) 24-12-1982	1,6,8	
A	GB-A- 712 125 (J. SCHWARZ)		**TECHNICAL FIELDS SEARCHED (Int. Cl.4)**
A	FR-A- 678 070 (O. FÖPPL)		C 21 D
A	STAHL UND EISEN, vol. 104, no. 14, 9th July 1984, pages 657-660, Düsseldorf, DE; E. von FINCKENSTEIN et al.: "Eigenspannungen beim Oberflächen-Feinwalzen"		
	--- -/-		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-12-1986	MOLLET G.H.J.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document

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EUROPEAN SEARCH REPORT

Application number

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Page 2

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A,D	WIRE JOURNAL INTERNATIONAL, vol. 16, no. 4, 1983, pages 50-61, Guildford, US; K. AIHARA et al.: "High-strength and high-fatigue limit zinc galvanized steel cord for ACSR" -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-12-1986	MOLLET G.H.J.

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E : earlier patent document, but published on, or after the filing date
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