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STEEL PRODUCT AND METHOD OF PRODUCING THE PRODUCT

The present invention relates to a steel product for use in the mining, construction and general manufacturing industries.

The present invention also relates to a method of producing the steel product.

The steel may be any one of low carbon steel, medium carbon steel and high strength low alloy steel (which is also described in the steel industry as a microalloy steel).

The term "low carbon steel" is understood herein to mean steel having less than 0.3 wt.% C, other elements such as Si and Mn that are added as deliberate additions to the steel, residual/incidental impurities and balance Fe.

The term "medium carbon steel" is understood herein to mean steel having 0.3-2.0 wt.% C, other elements such as Si and Mn that are added as deliberate additions to the steel, residual/incidental impurities, and balance Fe.

The term "residual/incidental impurities" covers elements such as Cu, Sn, Mo, Al, Zn, Ni, and Cr that may be present in very small concentrations, not as a consequence of specific additions of these elements but as a consequence of standard steelmaking practices. For example, the elements may be present as a consequence of the use of scrap steel to produce high strength low alloy, low carbon and medium carbon steels.

The term "high strength low alloy steel" is understood herein to mean steel of the following typical composition, in wt.%:

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C: 0.07-0.30;

Si: 0.9 or less;

Mn: 2.0 or less;

Mo: 0.35 or less;

5 Ti: 0.1 or less;

V: 0.1 or less;

Nb: 0.1 or less;

Cu: 0.1 or less;

N: 0.02 or less;

10 S: 0.05 or less;

Al: 0.05 or less;

Residual/incidental impurities: 1.0 or less; and

Fe: balance.

15 The term "residual/incidental impurities" in the
context of high strength low alloy steels is understood as
described above in relation to low and medium carbon steels.
The concentrations of elements such as Cu and Mo in the table
in the preceding paragraph are total concentrations, i.e. the
20 concentrations of these elements as a total of deliberate
additions and residual/incidental impurities.

The steel product may be any suitable product.

25 The steel product may be wire, rod, bar, or strip.

The steel product may be in the form of a steel
product that is made from any one of wire, rod, bar, and
strip.

30 The steel product may include any product, including
but not limited to reinforcement bar for concrete
construction, reinforcement mesh for the concrete construction
and mining industries made by welding together spaced-apart
35 parallel line wires and spaced-apart parallel cross-wires,
pipe made from steel strip, couplers for coupling together any
elongate products such as reinforcing bars, continuous

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spirals, ligatures for reinforcing cages for concrete columns and beams, fasteners (including screws, bolts etc.) made from steel bar, rock bolts made from steel bar, and other steel products used in tensile or compression or shear or flexural applications in the concrete construction, construction, mining or manufacturing industries.

The present invention is based on a surprising finding that it is possible to treat steel by heating steel (hereinafter referred to as "heat treatment") that has been mechanically worked (e.g. cold formed such as by cold rolling) and: (a) maintain or increase the ductility (for example, measured as elongation and described in the specification in terms of elongation and known by the term Agt (uniform elongation) when referring to reinforcing steels and often expressed as $Agt_{(-0.5\%)}$), (b) maintain or increase the yield stress (YS) (often expressed as Proof Stress (PS) for reinforcing steels) and (c) maintain or increase the tensile strength (TS) of the steel. This is a surprising finding because metallurgy teaches that heat treatment of mechanically-worked steel results in an increase in ductility and a decrease in the yield stress and a decrease in the tensile strength of the steel.

By way of example, the applicant found that steel that had been mechanically worked to reduce the transverse cross-sectional area of the steel by 5-30% and in some instances up to 75% and then heat treated at a temperature in a range of 150-750°C for a time period of 1 minute to 16 hours maintained and in many instances produced an increase in ductility of at least 25% relative to that of the mechanically worked steel and an increase in yield stress of at least 5% relative to that of the mechanically worked steel.

In general terms, the applicant found that mechanically worked steel could be heat treated at higher temperatures and for shorter times or at lower temperatures

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and for longer times to maintain or increase ductility, yield stress, and tensile strength.

It is noted that the invention is not confined to mechanical working that changes the transverse cross-sectional area of a feed steel or a steel product and also extends to situations where cold working changes the shape of the feed steel or the steel product.

Typically, and without limiting the scope of the present invention, specific steel chemistries and process routes and properties are summarised in the following table.

Steel Chemistry	Process Route	Cold Work	HT Temp and Time	YS (PS) - MPa	Elongation (Agt)%
HSLA	Cold work and HT	Less than 20% - could be up to or more than 35%	150-750°C and 5 mins - 16 hrs	Greater than 600 MPa	Greater than 1.5%
Low C	Cold work and HT	20-25% - could be up to or more than 45%	150-750°C and 5 mins- 16 hrs	Greater than 500 MPa	Greater than 1.5%
Medium C	Cold work and HT	20-75%	150-750°C and 5 mins- 16 hrs	750-1000 MPa	Greater than 1.5%

Nb - "HT" referred to in the above Table means "heat treatment".

The present invention is based on an extensive research and development program that has focused on testing a substantial number of samples of low carbon steels, medium carbon steels, and high strength low alloy steels. The samples included samples that were mechanically worked under different conditions and heat treated at different temperatures and for different times. The research and development program is discussed in a later section of the specification in more detail.

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The present invention provides a method of producing a steel product that includes heat treating a mechanically worked steel product and maintaining or increasing the ductility and maintaining or increasing the yield stress of the steel.

The present invention also provides a method of producing a steel product that includes heat treating a mechanically worked steel product and maintaining or increasing the ductility and maintaining or increasing the yield stress and maintaining or increasing the tensile strength of the steel.

The present invention also includes a mechanically worked and heat treated steel product. The steel product may be any one of the steel products described above, i.e. wire, rod, bar, or strip, and any steel product that is made from any one of wire, rod, bar, and strip and including the specific products mentioned above.

The invention provides an opportunity to use the same starting material, such as a high strength low alloy steel, low carbon steel, and medium carbon steel, and produce a range of required mechanical properties by appropriate selection of mechanical working and heat treatment time and heat treatment temperature.

In this regard, the present invention also provides a method of producing a steel product that includes selecting a feed steel as a starting material for the product and selecting mechanical working and heat treatment time and heat treatment temperature conditions of the feed steel or a product made from the feed steel to provide required mechanical properties for the product and carrying out mechanical working and heat treating steps and maintaining or increasing the ductility and maintaining or increasing the

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yield stress of the steel and producing the product with the required mechanical properties.

5 The invention provides an opportunity for small or large quantities of readily available steel materials to be used to manufacture:

10 (a) high strength (e.g. >750 MPa yield stress) and high ductility (e.g. Uniform Elongation > 1.5% Agt), bar, rod, wire or mesh; and

15 (b) medium strength (e.g. >500 MPa yield stress) and high ductility (e.g. Uniform Elongation > 1.5% Agt) bar, rod wire or mesh.

20 By way of example, a 750 MPa yield stress type (a) steel in accordance with the invention represents a potential material saving of 33% for the same performance as a conventional 500 MPa yield stress reinforcing steel in tensile applications. Therefore, the diameter of a reinforcing steel could be reduced from, say, 12 mm to approximately 9.8 mm for the same performance. Alternatively, using a bar of 12 mm in diameter and with a 750 MPa yield stress would allow an increase in performance of 50%, and hence e.g. a better
25 performing concrete column or beam for the same quantity of steel. A mesh manufactured from the material with the same properties and used in mining applications represents a potential material saving of at least 30% for the same performance and with consequent occupational health and safety
30 benefits, i.e. handling of a lighter product. Whilst not critical, being able to also increase the ductility is a potential benefit.

35 By way of further example, in the concrete construction industry, being able to manufacture 500 MPa mesh with >5% Agt allows approximately a 20% reduction in the amount of steel required in applications that require moment

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redistribution, e.g. many suspended floors. Steel fixing in Australia is currently charged at a \$/tonne rate, and therefore a reduction in the amount of steel to be fixed provides an opportunity to significantly reduce the installed cost of reinforcing. This same reduction would apply to high strength bar or wire reinforcing.

By way of further example, using a high tensile strength (650 MPa or greater yield stress), ductile mesh manufactured in this manner would potentially allow in the order of 20-25% reduction in the mass of steel required to reinforce a concrete slab on ground or tilt-up concrete products, for example.

Each of these above-described high tensile strength or medium tensile strength products have an added advantage of providing an opportunity to significantly reduce embodied energy (greenhouse gases) in the product and the potential to reduce concrete use in columns and beams and associated reductions in transport and other materials handling costs.

Elongation is a measure of ductility. Elongation is expressed herein as Uniform Elongation - Agt. The term "Uniform Elongation" is understood herein to be a measure of the ability of steel to deform both elastically and plastically before reaching its maximum tensile strength. The numerical amounts for elongation reported in the specification are the elongation of steel in percentage terms measured after the maximum tensile strength of the steel has been reached and dropped to 99.5% of the maximum tensile strength and expressed as $A_{gt(-0.5\%)}$. This method is used for reliability of measurement. Total elongation is also used as a measure of ductility of steel products, particularly sheet.

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The increase in elongation of the heat treated steel relative to that of the mechanically worked steel may be greater than 5%.

5 The increase in elongation of the heat treated steel may be greater than 10%.

 The increase in elongation of the heat treated steel may be greater than 15%.

10 The increase in elongation of the heat treated steel may be greater than 20%.

 The increase in elongation of the heat treated steel may be greater than 30%.

15 The increase in elongation of the heat treated steel may be greater than 50%.

20 The increase in elongation of the heat treated steel may be greater than 100%.

 The increase in elongation of the heat treated steel may be greater than 150%.

25 The increase in elongation of the heat treated steel may be greater than 200%.

 The increase in the yield stress of the heat treated steel relative to that of the mechanically worked steel may be greater than 5%.

30 The increase in the yield stress of the heat treated steel may be greater than 10%.

35 The increase in the yield stress of the heat treated steel may be greater than 15%.

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The increase in the yield stress of the heat treated steel may be greater than 20%.

5 The increase in the yield stress of the heat treated steel may be greater than 30%.

The increase in the yield stress of the heat treated steel may be greater than 40%.

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The heat treatment step may be carried out at any suitable temperature. There are a number of factors that may have an impact on the selection of the heat treatment temperature in any given situation. One factor is heat treatment time. The applicant has also found that each heat treatment temperature has a time window within which the yield stress and ductility are increased to a level above a desired minimum. This window narrows as the heat treatment temperature increases. Another factor is the steel composition. Another factor is the target properties, such as ductility and yield stress.

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The heat treatment step may be carried out at a temperature below the austenitising temperature of the steel. It is noted that in any given situation the actual temperature of the steel during the heat treatment will be a time-temperature dependent relationship and a function of the steel composition. Therefore, the temperature of the furnace may be above the austenitising temperature of the steel.

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The heat treatment step may be carried out at a temperature below 1000°C.

The heat treatment step may be carried out at a temperature below 800°C.

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The heat treatment step may be carried out at a temperature below 750°C.

5 The heat treatment step may be carried out at a temperature below 700°C.

The heat treatment step may be carried out at a temperature below 600°C.

10 The heat treatment step may be carried out at a temperature below 550°C.

The heat treatment step may be carried out at a temperature below 500°C.

15 The heat treatment step may be carried out at a temperature below 450°C.

20 The heat treatment step may be carried out at a temperature below 400°C.

The heat treatment step may be carried out at a temperature below 300°C.

25 The heat treatment step may be carried out at a temperature below 250°C.

The heat treatment step may be carried out at a temperature above 200°C.

30 The heat treatment step may be carried out at a temperature above 150°C.

35 The heat treatment step may be carried out at a temperature above the austenitising temperature of the steel provided the heat treatment time is selected to be sufficiently short to maintain or increase the yield stress

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and maintain or increase the ductility relative to the starting points for yield stress and tensile strength and ductility.

5 The heat treatment step may be carried out for any suitable time. There are a number of factors that may have an impact on the selection of the heat treatment time. As discussed above in relation to heat treatment temperature, these factors include heat treatment temperature and steel
10 composition and target properties and productivity.

 The heat treatment step may be carried out for less than 16 hours.

15 The heat treatment step may be carried out for less than 10 hours.

 The heat treatment step may be carried out for less than 6 hours.

20 The heat treatment step may be carried out for less than 5 hours.

25 The heat treatment step may be carried out for less than 4 hours.

 The heat treatment step may be carried out for greater than 1 hour.

30 The heat treatment step may be carried out for greater than 45 minutes.

 The heat treatment step may be carried out for greater than 30 minutes.

35 The heat treatment step may be carried out for greater than 10 minutes.

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The heat treatment step may be carried out for greater than 5 minutes.

5 The heat treatment step may be carried out for greater than 1 minute.

The heat treatment step may be carried out for greater than 30 seconds.

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The heat treatment step may be carried out in any suitable atmosphere. The atmosphere may be an oxidising atmosphere or a reducing atmosphere. By way of particular example, the heat treatment step may be carried out in air.

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The heat treatment step may be carried out without a protective atmosphere. This is an important advantage of the invention.

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The heat treatment step may be carried out using any suitable means. Specifically, any suitable source of heat energy may be used to carry out the heat treatment.

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The mechanically worked steel product may be any suitable form of product. The mechanically worked steel product may be in the form of any one of wire, rod, bar, or strip.

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The steel product may be in the form of any one of wire, rod, bar, or strip.

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The rod and bar products may range from products which have small to large aspect ratios of length to diameter. In other words, the rod and bar products may range from products which have diameters that are close to the length of the products to products that have diameters or transverse

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cross-sectional areas that are significantly less than the length of the products.

5 The steel product may be in the form of a steel product that is made from any one of wire, rod, bar, and strip. A non-exclusive range of steel products is set out above. One particular steel product of interest to the applicant is reinforcement mesh for the concrete construction and mining industries made by welding together spaced-apart
10 parallel line wires and spaced-apart parallel cross-wires. Another particular steel product of interest to the applicant is reinforcing bar of all kinds, such as in straight lengths and formed into ligatures or continuous spirals or other commonly available shapes (noting that there are many such
15 shapes). The invention and the properties achieved by the invention are not limited by the shape of the steel product.

The mechanically worked steel product may be a cold rolled or drawn or any other suitable mechanically worked
20 product that results in a change of cross-sectional shape of the product, without necessarily changing the transverse cross-sectional area, such that there has been energy input required to cause the shape change. For example, the shape change may be from a circular to an oval transverse cross-
25 section of the same cross-sectional area as the circular shape.

The mechanically worked steel product may be a cold rolled or drawn or any other suitable mechanically worked
30 product that has a reduced transverse cross-sectional area after it has been mechanically worked.

The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 2% less than
35 the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 5% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 10% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 15% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 20% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 40% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 50% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 60% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 70% less

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than the transverse cross-sectional area of the steel product before the mechanical working.

5 The method may include cooling the heat treated product from the heat treatment temperature at any suitable cooling rate. For example, the heat treated product may be quenched by being water-cooled. By way of further example, the heat treated product may be cooled in ambient air. The applicant has found that, in general, the cooling rate does
10 not have a significant impact on properties, namely ductility, yield stress and tensile strength. However, the applicant has found that quenching the heat treated product may have a significant impact on the properties in some situations, such as when quenching from heat treatment temperatures of at least
15 750°C after a particular time. In one example, after approximately 8 minutes at 750°C there was a sudden increase in tensile strength and a reduction in yield stress and A_{gt} . This response is typical of a steel that is heat treated at a temperature above the austenitising temperature. In this
20 example, there was a heat treatment window of up to 8 minutes for which subsequent quenching had no impact on properties.

The steel may be a low carbon steel, as described above.

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The steel may be a medium carbon steel, as described above.

The steel may be a high strength low alloy steel, as defined above.

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The high strength low alloy steel may contain greater than 0.040 wt.% V.

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The high strength low alloy steel may contain greater than 0.050 wt.% V.

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The high strength low alloy steel may contain greater than 0.060 wt.% V.

5 The high strength low alloy steel may contain greater than 0.005 wt.% N.

The high strength low alloy steel may contain greater than 0.015 wt.% N.

10 The high strength low alloy steel may contain greater than 0.018 wt.% N.

15 The high strength low alloy steel may contain other alloying elements, such as Nb.

The present invention provides a method of producing a steel product that includes:

- 20 (a) mechanically working a feed steel,
- (b) heat treating the mechanically worked feed steel and maintaining or increasing the ductility and maintaining or increasing the yield stress of the steel; and
- 25 (c) forming a steel product.

30 The method may include multiple sequences of steps (a) and (b) and (c).

The present invention provides a method of producing a steel product that includes:

- 35 (a) mechanically working a steel product, and
- (b) heat treating the mechanically steel product and maintaining or increasing the ductility and

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maintaining or increasing the yield stress of the steel.

5 The method may include multiple sequences of steps (a) and (b) .

The present invention provides a method of producing a steel product that includes:

10 (a) mechanically working a feed steel,

(b) forming the steel product, and

15 (c) heat treating the steel product and increasing or maintaining the ductility and maintaining or increasing the yield stress of the steel product.

20 The method may include multiple sequences of steps (a) and (b) and (c) .

The present invention provides a method of producing a steel product that includes:

25 (a) mechanically working a feed steel,

(b) forming the steel product, and

30 (c) heat treating the formed steel product and maintaining or increasing the ductility and maintaining or increasing the yield stress and tensile strength of the steel product.

35 The method may include multiple sequences of steps (a) and (b) and (c) .

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The increase in elongation of the heat treated steel may be greater than 5% relative to that of the mechanically worked feed steel.

5 The increase in elongation of the heat treated steel may be greater than 10%.

The increase in elongation of the heat treated steel may be greater than 20%.

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The increase in elongation of the heat treated steel may be greater than 30%.

15 The increase in elongation of the heat treated steel may be greater than 50%.

The increase in elongation of the heat treated steel may be greater than 100%.

20 The increase in elongation of the heat treated steel may be greater than 150%.

The increase in elongation of the heat treated steel may be greater than 200%.

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The increase in the yield stress of the heat treated steel may be greater than 10%.

30 The increase in the yield stress of the heat treated steel may be greater than 20%.

The increase in the yield stress of the heat treated steel may be greater than 30%.

35 The increase in the yield stress of the heat treated steel may be greater than 40%.

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The method may also include forming the steel product into another steel product.

5 The feed steel may be any one of low carbon steel, medium carbon steel, and high strength low alloy steel.

10 The feed steel may be in any suitable form. The feed steel may be in the form of any one of wire, rod, bar, or strip.

It is noted that the mechanical working step may comprise reducing the transverse cross-sectional area, i.e. the diameter, of wire, rod and bar.

15 It is also noted that the mechanical working step may comprise reducing the transverse cross-sectional area, i.e. the thickness, of the strip.

20 It is also noted that the mechanical working step may result in a change of cross-sectional shape of the product, without necessarily changing the transverse cross-sectional area, such that there has been energy input required to cause the shape change.

25 The steel product may be any suitable form of product.

30 The steel product may be in the form of a steel product that is made from any one of wire, rod, bar, and strip.

35 The mechanical working step (a) may include cold rolling or drawing or any other suitable mechanical working step that reduces the transverse cross-sectional area of the feed steel.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 2% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 5% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 10% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 15% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 20% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 40% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 50% less than the transverse cross-sectional area of the steel product before the mechanical working.

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The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 60% less

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than the transverse cross-sectional area of the steel product before the mechanical working.

5 The reduced transverse cross-sectional area of the mechanically worked steel product may be at least 70% less than the transverse cross-sectional area of the steel product before the mechanical working.

10 The heat treatment step may be carried out at a temperature below the austenitising temperature of the steel.

 The heat treatment step may be carried out at a temperature below 1000°C.

15 The heat treatment step may be carried out at a temperature below 800°C.

 The heat treatment step may be carried out at a temperature below 750°C.

20 The heat treatment step may be carried out at a temperature below 700°C.

25 The heat treatment step may be carried out at a temperature below 600°C.

 The heat treatment step may be carried out at a temperature below 550°C.

30 The heat treatment step may be carried out at a temperature below 500°C.

 The heat treatment step may be carried out at a temperature below 450°C.

35 The heat treatment step may be carried out at a temperature below 400°C.

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The heat treatment step may be carried out at a temperature below 300°C.

5 The heat treatment step may be carried out at a temperature below 250°C.

The heat treatment step may be carried out at a temperature above 200°C.

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The heat treatment step may be carried out at a temperature above 150°C.

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The heat treatment step may be carried out for less than 16 hours.

The heat treatment step may be carried out for less than 10 hours.

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The heat treatment step may be carried out for less than 6 hours.

The heat treatment step may be carried out for less than 5 hours.

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The heat treatment step may be carried out for less than 4 hours.

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The heat treatment step may be carried out for greater than 1 hour.

The heat treatment step may be carried out for greater than 45 minutes.

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The heat treatment step may be carried out for greater than 30 minutes.

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The heat treatment step may be carried out for greater than 10 minutes.

5 The heat treatment step may be carried out for greater than 5 minutes.

The heat treatment step may be carried out for greater than 1 minute.

10 The heat treatment step may be carried out for greater than 30 seconds.

15 The heat treatment step (b) may be carried out in any suitable atmosphere.

The present invention also provides a steel product made by the above method.

20 The steel product may have a yield stress of at least 500 MPa yield stress and a Uniform Elongation of at least 1.5% Agt.

25 The present invention also provides a mechanically worked and heat treated high strength low alloy steel product that has a steel composition, an elongation and a yield stress as described above.

30 The steel product may have a tensile strength as described.

35 The present invention also provides a mechanically worked and heat treated low carbon steel product that has a steel composition, an elongation and a yield stress as described above.

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The steel product may have a tensile strength as described.

5 The present invention also provides a mechanically worked and heat treated medium carbon steel product that has a steel composition, an elongation and a yield stress as described above.

10 The steel product may have a tensile strength as described.

15 The steel product may be in the form of a steel product that is made from any one of wire, rod, bar, and strip as described above.

20 By way of particular example, the steel product is a mesh product that includes parallel line wires and parallel cross-wires welded together at the intersections of the wires, with the wires being steel wires, with the wires being at least 3 mm in diameter, and with the wires having been mechanically worked and heat treated prior to being welded together to form the mesh, such that the wires have a yield stress of at least 650 MPa and a Uniform Elongation of at least 1.5% Agt.

25 By way of further particular example, the steel product is a mesh product that includes parallel line wires and parallel cross-wires welded together at the intersections of the wires, with the wires being at least 3 mm in diameter, 30 with the wires being steel wires, with the wires having been mechanically worked prior to being welded together to form the mesh, and with the mesh being heat treated, such that the wires having a yield stress of at least 650 MPa and a Uniform Elongation of at least 1.5% Agt.

35 By way of particular example, the steel product is a ligature formed from a steel wire that is at least 3 mm in

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diameter, and with the wire having been mechanically worked and heat treated prior to being formed into the ligature, such that the wires have a yield stress of at least 650 MPa and a Uniform Elongation of at least 1.5% Agt.

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By way of particular example, the steel product is a ligature formed from a steel wire that is at least 3 mm in diameter, and with the wire having been mechanically worked prior to being formed into the ligature, with the ligature being heated treated, such that the wires have a yield stress of at least 650 MPa and a Uniform Elongation of at least 1.5% Agt.

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The present invention is described further with reference to the accompanying Figures 1-33 which are graphs of different combinations of yield stress (Proof Stress - MPa), tensile strength (MPa), elongation (measured as Uniform Elongation - A_{gt}), and heat treatment time for low carbon steel, medium carbon steel and high strength low alloy samples treated in accordance with the invention.

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The present invention is based on an extensive research and development program that focused on testing a substantial number of samples of low carbon steel, medium carbon steel and high strength low alloy. The samples included samples mechanically worked under different conditions and heat treated at different temperatures and for different times. A key finding of the research and development program was that mechanical working of the steel samples was critical to maintaining or obtaining improvements in elongation in subsequent heat treatment of the samples and also obtaining improvements in or maintaining yield stress and tensile strength in subsequent heat treatment of the samples.

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The research and development program was carried out on steel wire suitable for use in the manufacture of reinforcing mesh and other reinforcement products for the

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mining and construction industries. The steel wire was made from low carbon steel, medium carbon steel, and high strength low alloy steel. The steel wire was made by rolling a larger diameter steel rod or wire to smaller diameters.

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The following is a summary of the research and development program in relation to low carbon steel, medium carbon steel, and high strength low alloy steel.

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- Steel compositions - High strength low alloy steel, low carbon steel and medium carbon steel. Examples of the steel compositions are set out below.

High Strength Low Alloy

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C	Mn	Si	P	S	Cu	Ni	Cr	Mo	V	Al	Nb	Ti	CE
.17	1.10	.2	.013	.040	.28	.07	.11	.01	.102	.002	.001	.001	.42
.18	1.06	.25	.014	.046	.28	.07	.10	.01	.093	.002	.001	.001	.42

Low Carbon

C	P	Mn	Si	S	Ni	Cr	Mo	Cu	Al-T	B
.06	.006	.50	.15	.009	.006	.012	.001	.014	.002	.0003
.18	.010	.71	.20	.012	.005		.001	.008	.001	.0003

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Medium Carbon

C	P	Mn	Si	S	Ni	Cr	Mo	Cu	Al-T	B
.31	.018	.70	.24	.012	.002	.010	.001	.004	.001	.0003

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- Initial rod product - conventional AS 1442 or similar rolling procedure in a rod mill to produce a range of different diameter rod samples - the rod samples were then cold rolled to smaller diameter wires to form test samples. The samples included (a) 10 mm diameter rod rolled to 9.5 mm wire, (b) 8 mm diameter rod rolled to 7.7 mm, 7.6 mm, 7.5 and 6.75 mm wire, (c) 10.5 mm rod rolled to 9.5 mm, (d) 8.5 mm rod rolled to 6.75 mm, (e) 12 mm diameter rod rolled to 10.7 mm wire, (f) 8.5 mm diameter rod rolled to 7.6 mm wire, (g) 5.5 mm diameter

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rod rolled to 4.75 mm wire with was subsequently
straightened, (h) 5.5 mm diameter rod rolled to 4.75 mm
wire which was subsequently straightened using a smaller
diameter straightening roll than the straightening roll
used for the item (h) samples, and (i) 5.5 mm diameter
rod rolled to 3.06 mm wire.

- Heat treatment furnace - a fan forced air furnace
and a resistance heated furnace.
- Heat treatment temperatures - see Figures.
- Heat treatment times - see Figures.
- Air cool for samples having test data reported in
Figures 1-21 and 26-33 and water quench for samples
having test data reported in Figures 22-25.
- Sample size - approximately 300 mm long
- Testing procedures - tensile tests on Instron
machine and elongation determined via an extensometer.
The results in the Figures include graphs of proof stress
(PS), with yield stress reported as Proof stress,
elongation reported as Uniform Elongation ($A_{gt(-0.5\%)}$), and
tensile strength (TS).

The results of the research work are summarised in
part in Figures 1-33 of the specification which are described
and discussed below. It is noted that Figures 1-25 focus on
work on high strength low alloy steel ("HSLA") samples,
Figures 26-32 focus on low carbon steel samples, and Figure 33
focuses on medium carbon steel samples.

Figure 1 is a graph of elongation (A_{gt}) versus heat
treatment time (0-30 minutes) for HSLA samples heat treated at
300, 400, 500, 600, and 700°C, with the samples comprising 9.5

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mm diameter wire samples cold rolled from 10 mm diameter rod in accordance with the invention. It is evident from Figure 1 that the ductility of the samples increased with heat treatment time at each heat treatment temperature, with the rate of increase in ductility increasing with heat treatment temperature.

Figure 2 is a graph of yield stress (Proof Strength - MPa) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 300, 400, 500, 600, and 700°C, with the samples comprising 9.5 mm diameter wire samples cold rolled from 10 mm diameter rod in accordance with the invention. It is evident from Figure 2 that there was an increase in yield stress of the cold drawn samples at short heat treatment times at each of the heat treatment temperatures. The yield stress of the samples heat treated at the higher temperatures decreased (e.g. 500, 600, and 700°C) as the heat treatment times increased. However, there was no decrease in yield stress with heat treatment time for the samples that were heat treated at lower temperatures (300 and 400°C). The increase in yield stress was achieved with relatively short heat treatment times across the range of heat treatment temperatures. This is potentially significant in terms of processing times and costs.

Figure 3 is a graph of tensile strength (MPa) versus heat treatment time (0-30 minutes) for samples heat treated at 300, 400, 500, 600, and 700°C, with the samples comprising 9.5 mm diameter HSLA wire samples mechanically worked by being cold rolled from 10 mm diameter rod in accordance with the invention. The cold rolling amounts to a 9.75% reduction in transverse cross-sectional area. It is evident from Figure 3 that there was an increase in tensile strength of the cold rolled samples at short (less than 4 minutes) heat treatment times at each of the heat treatment temperatures. The tensile strength of the samples that were heat treated at the higher temperatures (e.g. 500, 600, and 700°C) decreased as the heat

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treatment times increased. However, there was no decrease in tensile strength with heat treatment time for the samples that were heat treated at lower temperatures (300 and 400°C). In addition, the increase in tensile strength was achieved with relatively short heat treatment times across the range of heat treatment temperatures. This is potentially significant in terms of processing times and costs.

Figure 4 includes a graph of elongation (measured as Uniform Elongation - Agt) versus heat treatment time (0-5 hours) for 9.5 mm diameter HSLA wire samples cold rolled from 10 mm diameter rod and heat treated at 300°C in accordance with the invention. The cold rolling amounts to a 9.75% reduction in transverse cross-sectional area. This graph is described as the "N10PLUS" curve in the Figure. Figure 4 also includes comparative data for 6.75 mm diameter low carbon steel wire samples cold rolled from 8.5 mm diameter rod and heat treated in the same way. The cold rolling amounts to a 37% reduction in transverse cross-sectional area. This graph is described as the "6.75EX8.5" curve in Figure 4. Figure 4 illustrates increases in ductility that might be expected as a consequence of the heat treatment of either steel samples.

Figure 5 includes graphs of yield stress (reported as Proof Stress - MPa) versus heat treatment time (0-5 hours) for the Figure 4 samples (HSLA and low carbon steel) heat treated at 300°C.

Figure 6 includes graphs of tensile strength (MPa) versus heat treatment time (0-5 hours) for the Figure 4 samples (HSLA and low carbon steel) heat treated at 300°C.

It is evident from Figures 4-6 that there was an increase in each of ductility, yield stress, and tensile strength of the N10PLUS HSLA samples whereas there was the conventional response of an increase in ductility and a decrease in yield stress and tensile strength of the 6.75EX8.5

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low carbon steel samples. An interesting point in relation to the N10PLUS samples is that the results were achieved at a low heat treatment temperature of 300°C.

5 Figures 4, 5 and 6 include dotted line sections. The experimental work reported in these Figures was very early work and the applicant chose the heat treatment times of 1.15, 2 and 4 hours because conventional wisdom indicates that at least 1.2 hours would be required to produce a normal reaction
10 for a low carbon steel, i.e. an increase in ductility and a decrease in yield stress and tensile strength - a normal recovery heat treatment reaction. When the applicant treated the N10PLUS samples and realized there was a strength increase, the applicant then investigated the shorter heat
15 treatment times for this material. This also prompted the applicant to look at shorter heat treatment times for the 6.75 mm material (and subsequently all others) and the applicant found an increase for the low carbon steels at the shorter times. Figures 26, 27 and 28 demonstrate the increase in
20 ductility, yield stress and tensile strength. This was a different material rolled to 6.75 mm and hence the different starting strengths. Figures 29-32, which were low carbon steels treated at 500°C for the short times showed the same increases in ductility, yield stress and tensile strength for
25 short heat treatment times.

Figure 7 is a graph of elongation (Agt) versus heat treatment temperature (0-500°C) for HSLA samples heat treated for 4 hours, with the samples comprising 7.5 mm, 7.6 mm, and
30 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 7 that there was an increase in ductility in the
35 cold drawn samples at heat treatment temperature greater than 200°C and that the ductility increased as the heat treatment temperature increased.

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Figure 8 is a graph of yield stress (Proof Stress MPa) versus heat treatment temperature (0-500°C) for HSLA samples heat treated for 4 hours, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 8 that the yield stress of each of the cold drawn samples initially increased and then decreased as the heat treatment temperature increased. The yield stress was higher for the samples having higher cold reductions. The shapes of the graphs in Figure 8 indicate that there is a window of heat treatment temperatures, namely a window in the range of 150-400°C, in which there was a significant increase in yield stress of the samples. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment.

Figure 9 is a graph of tensile strength (MPa) versus heat treatment temperature for HSLA samples heat treated for 4 hours, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 9 that the tensile strength of each of the cold rolled samples initially increased and then decreased as the heat treatment temperature increased. The tensile strength was higher for the samples having higher cold reductions. The shapes of the graphs in Figure 9 indicate that there was a window of heat treatment temperatures, namely a window in the range of 150-350°C, in which there was a significant increase in tensile strength of the samples.

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Figure 10 is a graph of elongation (Agt) versus heat treatment time (0-7 hours) for HSLA samples heat treated at 100°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 10 that there was an overall slight decrease in ductility in the cold drawn samples across the range of heat treatment times. This decrease is consistent with a strain ageing mechanism. Basically, the ductility change was conventional and the teaching is that the heat treatment temperature of 100°C was too low. The ductility was higher for the samples having lower cold reductions.

Figure 11 is a graph of yield stress (Proof Strength - MPa) versus heat treatment time (0-7 hours) for HSLA samples heat treated at 100°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold drawn from 8 mm diameter rod in accordance with the invention. The samples were cold drawn to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 11 that there was an increase (albeit not substantial) in yield stress in the cold drawn samples across the range of heat treatment times. The yield stress was higher for the samples having higher cold reductions.

Figure 12 is a graph of tensile strength (MPa) versus heat treatment time (0-7 hours) for HSLA samples heat treated at 100°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 12 that there was a slight change in tensile strength in the cold rolled samples across the range

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of heat treatment times. The tensile strength was higher for the samples having higher cold reductions.

Figure 13 is a graph of elongation (Agt) versus heat treatment time (0-16 hours) for HSLA samples heat treated at 300°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 13 that after an initial sudden decrease in ductility (which is consistent with normal ageing) there was a significant initial increase in ductility in a relatively short heat treatment time (up to 30 minutes) at 300°C for each of the samples and that the ductility tended to level out after around 3 hours of heat treatment at that temperature. The ductility was higher for the samples having lower cold reductions.

Figure 14 is a graph of yield stress (Proof Stress - MPa) versus heat treatment time (0-16 hours) for HSLA samples heat treated at 300°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 14 that there was a significant initial increase in yield stress in a relatively short heat treatment time (0-45 minutes) at 300°C for each of the samples and that the yield stress tended to level out after around 45 minutes of heat treatment at that temperature. The yield stress was higher for the samples having higher cold reductions. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment.

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Figure 15 is a graph of tensile strength (MPa) versus heat treatment time (0-16 hours) for HSLA samples heat treated at 300°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 15 that there was a significant initial increase in tensile strength in a relatively short heat treatment time (0-45 minutes) at 300°C for each of the samples and that the tensile strength tended to level out after around 45 minutes of heat treatment at that temperature. The tensile strength was higher for the samples having higher cold reductions. The tensile strength of the samples was higher across the whole heat treatment time range than the tensile strength of the samples prior to heat treatment.

Figure 16 is a graph of elongation (Agt) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 300°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. These samples were cold rolled and heat treated under the same conditions as the Figure 13 samples. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. This graph focuses on the first 30 minutes of heat treatment time highlighted in the discussion of Figure 13. It is evident from Figure 16 that after an initial decrease in ductility (which is consistent with normal ageing) there was a steady increase in ductility with heat treatment time at 300°C for each of the samples, with the ductility being higher for the samples having lower cold reductions.

Figure 17 is a graph of yield stress (Proof Stress - MPa) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 300°C, with the samples comprising 7.5

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mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. These samples were cold rolled and heat treated under the same conditions as the Figure 14 samples. This graph focuses on the first 30 minutes of heat treatment time highlighted in the discussion of Figure 14. It is evident from Figure 17 that there was generally a steady increase in yield stress with heat treatment time at 300°C for each of the samples. The yield stress was higher for the samples having higher cold reductions. The increase in yield stress is well above what would be expected from normal strain ageing. Normal strain ageing is detrimental because it leads to a reduction in ductility.

Figure 18 is a graph of tensile strength (MPa) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 300°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. These samples were cold rolled and heat treated under the same conditions as the Figure 15 samples. This graph focuses on the first 30 minutes of heat treatment time highlighted in the discussion of Figure 15. It is evident from Figure 18 that there was a steady increase in tensile strength with heat treatment time at 300°C for each of the samples. The tensile strength was higher for the samples having higher cold reductions.

Figure 19 is a graph of elongation (Agt) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 500°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled

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to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 19 that after an initial decrease in ductility (which is consistent with normal ageing) there was a steady increase in ductility with heat treatment time at 500°C for each of the samples, with the ductility being higher for the samples having lower cold reductions.

Figure 20 is a graph of yield stress (Proof Stress - MPa) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 500°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 20 that there was an initial increase in yield stress at the heat treatment temperature of 500°C for each of sample, with the yield stress of each sample reaching a maximum yield stress after 10 minutes. The yield stress of each sample decreased with heat treatment times greater than 10 minutes. The yield stress was higher for the samples having higher cold reductions. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment.

Figure 21 is a graph of tensile strength (MPa) versus heat treatment time (0-30 minutes) for HSLA samples heat treated at 500°C, with the samples comprising 7.5 mm, 7.6 mm, and 7.7 mm diameter wire samples cold rolled from 8 mm diameter rod in accordance with the invention. The samples were cold rolled to different extents, with the highest reduction being around 12% in transverse cross-sectional area. It is evident from Figure 21 that there was an initial increase in tensile strength at the heat treatment temperature of 500°C for each sample, with the tensile strength of each sample reaching a maximum tensile strength

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after 10 minutes, and the tensile strength of each sample decreasing with heat treatment times greater than 10 minutes. The tensile strength was higher for the samples having higher cold reductions.

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Figure 22 is a graph of elongation (Agt) versus heat treatment time (0-20 minutes) for 6.75 mm diameter HSLA wire samples cold rolled from 8 mm diameter rod and heat treated at 750°C over a time period up to 20 minutes and then water quenched in accordance with the invention. The cold rolling amounts to a 29% reduction in transverse cross-sectional area. It is evident from Figure 22 that after an initial decrease in ductility (which is consistent with normal strain ageing) there was a steady increase in ductility with heat treatment time at 750°C until 7 minutes, followed by a sudden decrease in ductility and a sudden increase before levelling out at around 10-12 minutes. It is evident from Figure 22 that water quenching heat treated samples had no detrimental impact on the ductility at heat treatment times between 2 and 7 minutes. It is evident from a comparison of the results in Figure 22 and the results in Figure 19 for 7.5, 7.6, 7.7 mm material cold rolled from 8 mm diameter rod and heat treated at 500°C that the ductility of the 6.75 mm material of Figure 22 was higher than for the 7.5, 7.6, 7.7 mm material of Figure 19. This finding is contrary to the evidence for the 7.5, 7.6, 7.7 mm material shown in Figure 19 where the ductility decreased with increasing cold reduction. This may be a consequence of the higher heat treatment temperature for the 6.75 mm material generating greater ductility.

30

Figure 23 is a graph of yield stress (Proof Strength - MPa) and tensile strength (MPa) versus heat treatment time (0-20 minutes) for 6.75 mm diameter HSLA wire samples cold rolled from 8 mm diameter rod and heat treated at 750°C and then water quenched in accordance with the invention. It is evident from Figure 23 that water quenching samples that were heat treated for up to 7 minutes and then quenched had an

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improvement in yield stress and tensile strength. Heat treatment times less than 8 minutes followed by quenching resulted in a significant increase in tensile strength and a significant reduction in yield stress. It is evident from Figure 23 that there was a heat treatment time window of up to 7 minutes at the heat treatment temperature in which there was an improvement in yield stress and tensile strength. Quenching does not destroy mechanical properties. An advantage of quenching is that the product is immediately available.

Figure 24 is a graph of elongation (Agt) versus heat treatment time (0-20 minutes) for 6.75 mm diameter HSLA wire samples cold rolled from 8 mm diameter rod and heat treated at 500°C and then water quenched in accordance with the invention. It is evident from Figure 24 that after an initial decrease in ductility (which is consistent with normal strain ageing) there was a steady increase in ductility with heat treatment time at 500°C. It is evident from Figure 24 that water quenching heat treated samples had no detrimental impact on ductility at heat treatment times greater than 5 minutes. In addition, it is also evident that the higher heat treatment temperature of 750°C for the samples referred to in the preceding paragraph generated approximately 2% greater ductility than for the samples heat treated at 500°C.

Figure 25 is a graph of yield stress (Proof Strength - MPa) and tensile strength (MPa) versus heat treatment time (0-20 minutes) for 6.75 mm diameter HSLA wire samples cold rolled from 8 mm diameter rod and heat treated at 500°C and then water quenched in accordance with the invention. It is evident from Figure 25 that water quenching heat treated samples had substantially no impact on yield stress and tensile stress. In other words, at this heat treatment temperature there is no downside in water quenching treated steel. It is noted nevertheless that these heat treatment conditions produced an increase in yield stress and tensile strength.

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Figures 26-31 focus on the results of research and development work on low carbon steel samples.

5 Figure 26 is a graph of elongation (Agt) versus heat treatment time (0-30 minutes) for samples heat treated at 500°C, with the samples comprising 9.5 mm and 6.75 mm diameter low carbon steel wire samples cold rolled from 10 mm diameter and 8.5 mm rod respectively in accordance with the invention.
10 The cold rolling amounts to a 18% and 37% reduction in transverse cross-sectional area, respectively. It is evident from Figure 26 that after an initial decrease in ductility (which is consistent with normal strain ageing) there was a steady increase in ductility with heat treatment time at
15 500°C.

 Figure 27 is a graph of yield stress (Proof Strength - MPa) versus heat treatment time (0-30 minutes) for samples heat treated at 500°C, with the samples comprising 9.5 mm and
20 6.75 mm diameter low carbon steel wire samples cold rolled from 10.5 mm diameter and 8.5 mm rod respectively in accordance with the invention. The cold rolling amounts to a 18% and 37% reduction in transverse cross-sectional area, respectively. It is evident from Figure 27 that the yield
25 stress of the more heavily mechanically worked sample (i.e. the 6.75 mm sample) initially increased (up to 2 minutes heat treatment time) and then decreased with heat treatment time, with a period of 7 minutes treatment time passing before the yield stress decreased to the initial start strength, i.e.
30 cold worked strength. The initial increase in yield stress is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in yield stress. It is also evident from Figure 27 that the yield stress of the less heavily mechanically worked
35 sample (i.e. the 9.5 mm sample) was not adversely affected by heat treatment for up to 8 minutes. When considered in conjunction with Figure 26, the yield stress results reported

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in Figure 27 are a significant result because the results indicate that it is possible to heat treat such heavily worked steel and achieve the Figure 26 increase in ductility without a loss of yield stress and more importantly with a possible increase in yield stress.

Figure 28 is a graph of tensile strength (MPa) versus heat treatment time (0-30 minutes) for samples heat treated at 500°C, with the samples comprising 9.5 mm and 6.75 mm diameter low carbon steel wire samples cold rolled from 10.5 mm diameter and 8.5 mm rod respectively in accordance with the invention. The cold rolling amounts to a 18% and 37% reduction in transverse cross-sectional area, respectively. It is evident from Figure 28 that the tensile strength of the less heavily mechanically worked sample (i.e. the 9.5 mm sample) initially increased (up to 8 minutes heat treatment time) and then decreased with heat treatment time. The initial increase in tensile strength is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in tensile strength. When considered in conjunction with Figures 26 and 27, the Figure 28 result is a significant result because it indicates that it is possible to heat treat such heavily worked steel and achieve the Figure 26 increase in ductility and the Figure 27 increase in yield stress without a loss of tensile strength.

Figure 29 is a graph of yield stress (Proof Strength - MPa), tensile strength (MPa), and elongation (A_{gt}) versus heat treatment time (0-15 minutes) for samples heat treated at 500°C, with the samples comprising 10.7 mm diameter low carbon steel wire samples cold rolled from 12 mm diameter rod in accordance with the invention. The cold rolling amounts to a 20% reduction in transverse cross-sectional area of the samples. The plots for each parameter are shown as lines of best fit for the actual data points. It is evident from Figure 29 that yield stress, tensile strength and ductility

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increased steadily with heat treatment time. The increase in yield stress is a surprising result. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment.

Figure 30 is a graph of yield stress (Proof Strength - MPa), tensile strength (MPa), and elongation (A_{gt}) versus heat treatment time (0-15 minutes) for samples heat treated at 500°C, with the samples comprising 8.5 mm diameter low carbon steel wire samples cold rolled from 7.6 mm diameter rod in accordance with the invention. The cold rolling amounts to a 20% reduction in transverse cross-sectional area of the samples. The plots for each parameter are shown as lines of best fit for the actual data points. It is evident from Figure 30 that yield stress and tensile strength initially increased with heat treatment time and reached a peak around 5 minutes and then gradually decreased with longer heat treatment times. The initial increase in yield stress is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in yield stress. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment. It is also evident from Figure 30 that ductility increased steadily with heat treatment time.

Figure 31 is a graph of yield stress (Proof Strength - MPa), tensile strength (MPa), and elongation (A_{gt}) versus heat treatment time (0-15 minutes) for samples heat treated at 500°C, with the samples comprising 4.75 mm diameter low carbon steel wire samples cold rolled from 5.5 mm diameter rod in accordance with the invention. The wire samples were passed through a straightener before being heat treated. The cold rolling amounts to a 25% reduction in transverse cross-sectional area of the samples. The plots for each parameter are shown as lines of best fit for the actual data points. It

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is evident from Figure 31 that yield stress and tensile strength initially increased quite quickly with heat treatment time and reached a peak around 2-3 minutes and then gradually decreased with longer heat treatment times. The initial
5 increase in yield stress is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in yield stress. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior
10 to heat treatment. It is also evident from Figure 31 that ductility increased steadily with heat treatment time.

Figure 32 is a graph of yield stress (Proof Strength - MPa), tensile strength (MPa), and elongation (A_{gt}) versus
15 heat treatment time (0-15 minutes) for samples heat treated at 500°C, with the samples comprising 4.75 mm diameter low carbon steel wire samples cold rolled from 5.5 mm diameter rod in accordance with the invention. The wire samples were passed through a straightener before being heat treated. The cold
20 rolling amounts to a 25% reduction in transverse cross-sectional area of the samples. The only difference between the experimental procedure for this experiment and the experiment reported in Figure 31 relates to the type of straightener used. The straightening roll was a smaller
25 diameter straightening roll than the straightening roll used for the item (h) samples. The plots for each parameter are shown as lines of best fit for the actual data points. It is evident from Figure 32 that yield stress and tensile strength initially increased quite quickly with heat treatment time and
30 reached a peak around 2-3 minutes and then gradually decreased with longer heat treatment times. The initial increase in yield stress is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in yield stress. The yield stress of the samples
35 was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment. It is also evident from Figure 32 that ductility increased

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steadily with heat treatment time. The experimental results in Figures 31 and 32 are very similar, save that the yield stress, tensile strength and elongation are somewhat higher with the Figure 31 straightener than the Figure 32 straightener.

Figure 33 is a graph of yield stress (Proof Strength - MPa), tensile strength (MPa), and elongation (A_{gt}) versus heat treatment time (0-15 minutes) for samples heat treated at 500°C, with the samples comprising 3.06 mm diameter medium carbon steel wire samples cold rolled from 5.5 mm diameter rod in accordance with the invention. The cold rolling amounts to a 69% reduction in transverse cross-sectional area, respectively, of the samples. The plots for each parameter are shown as lines of best fit for the actual data points. It is evident from Figure 33 that yield stress initially increased quite quickly with heat treatment time and reached a peak around 3 minutes and then gradually decreased with longer heat treatment times. The initial increase in yield stress is a surprising result and indicates that there is a heat treatment window in which it is possible to achieve an increase in yield stress. The yield stress of the samples was higher across the whole heat treatment temperature range than the yield stress of the samples prior to heat treatment. It is also evident from Figure 33 that ductility increased steadily with heat treatment time.

The experimental work carried out by the applicant indicates that there is no difference in the way in which the invention works with ribbed and smooth wires treated in accordance with the invention.

In general terms, as illustrated by the results of the research work summarised in the Figures, the applicant found surprisingly that the ductility (measured as elongation), the yield stress, and the tensile strength of the wire of high strength low alloy, medium carbon, and low carbon

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steels could be increased as a consequence of a combination of mechanical working and heat treatment. The finding is a significant finding for the following reasons:

- 5 • It is possible to significantly reduce the amount of steel required to manufacture products without a loss of force capacity of the steel in the products. The reduced amount of steel required for products improves the economics of construction and reduces the carbon
10 footprint.
- There is an opportunity for higher strength and ductility products.
- 15 • There is a possibility of changing the design and resultant cost of composite products that are made from the steel products. One example is steel reinforced concrete products used in the construction industry. The invention may make it possible to reduce the amount of
20 steel and/or the amount of concrete used in these products or to increase the structural performance of these products for a given amount of steel.
- The method is inexpensive in that it can be carried
25 out with low capital and operating costs.

 The present invention can be used at different stages in the manufacture of end-use products and therefore provides considerable flexibility. For example, steel wire
30 can be processed in accordance with the invention to increase the yield stress and ductility of the wire and then coiled.

 The coiled product can be formed into end use products such as spirals, ligatures etc. Alternatively,
35 standard wire can be produced and coiled and then processed to produce products such as mesh sheets and ligatures etc. and these products can be processed in accordance with the

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invention to increase the yield stress and ductility of the products.

5 Many modifications may be made to the invention described above without departing from the spirit and scope of the invention.

10 By way of example, the research and development program reported above has focused on wire. However, the view of the applicant is that the results are found with wire should translate to rod, bar, and strip steel products.

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CLAIMS

1. A method of producing a steel product includes heat
treating a mechanically worked steel product and maintaining
5 or increasing the ductility and maintaining or increasing the
yield stress of the steel.

2. A method of producing a steel product includes heat
treating a mechanically worked steel product and maintaining
10 or increasing the ductility and maintaining or increasing the
yield stress and maintaining or increasing the tensile
strength of the steel.

3. The method defined in claim 1 or claim 2 wherein the
15 increase in ductility, measured as elongation, of the heat
treated steel relative to that of the mechanically worked
steel is greater than 5%.

4. The method defined in any one of the preceding
20 claims wherein the increase in the yield stress of the heat
treated steel relative to that of the mechanically worked
steel is greater than 5%.

5. A method of producing a steel product includes:

25

(a) mechanically working a feed steel, and

(b) heat treating the mechanically worked feed
steel and maintaining or increasing the
30 ductility and maintaining or increasing the
yield stress of the steel; and

(c) forming a steel product.

35 6. The method defined in claim 5 wherein the mechanical
working step (a) includes cold rolling or drawing or any other
suitable mechanical working step that reduces the transverse
cross-sectional area of the feed steel.

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7. The method defined in claim 5 wherein the mechanical working step (a) includes cold rolling or drawing or any other suitable mechanical working step that changes the cross-sectional shape of the feed steel, without necessarily changing the transverse cross-sectional area, such that there has been energy input required to cause the shape change.

8. A method of producing a steel product includes:

- (a) mechanically working a steel product, and
- (b) heat treating the mechanically worked steel product and increasing the ductility and maintaining or increasing the yield stress of the steel.

9. The method defined in claim 8 wherein the mechanical working step (a) includes cold rolling or drawing or any other suitable mechanical working step that reduces the transverse cross-sectional area of the steel product.

10. The method defined in claim 8 wherein the mechanical working step (a) includes cold rolling or drawing or any other suitable mechanical working step that changes the cross-sectional shape of the feed steel, without necessarily changing the cross-sectional area, such that there has been energy input required to cause the shape change.

11. A method of producing a steel product includes:

- (a) mechanically working a feed steel,
- (b) forming the steel product, and

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(c) heat treating the steel product and increasing the ductility and maintaining or increasing the yield stress of the steel product.

5 12. A method of producing a steel product includes:

(a) mechanically working a feed steel,

(b) forming the steel product, and

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(c) heat treating the formed steel product and increasing the ductility and maintaining or increasing the yield stress and tensile strength of the steel product.

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13. The method defined in claim 11 or claim 12 wherein the mechanical working step (a) includes cold rolling or drawing or any other suitable mechanical working step that reduces the transverse cross-sectional area of the feed steel.

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14. The method defined in claim 11 or claim 12 wherein the mechanical working step (a) includes cold rolling or drawing or any other suitable mechanical working step that changes the cross-sectional shape of the feed steel, without necessarily changing the transverse cross-sectional area, such that there has been energy input required to cause the shape change.

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15. The method defined in any one of the preceding claims wherein the steel is a high strength low alloy steel.

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16. The method defined in any one of the preceding claims wherein the steel is a low carbon steel.

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17. The method defined in any one of the preceding claims wherein the steel is a medium carbon steel.

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18. A method of producing a steel product that includes selecting a feed steel as a starting material for the product and selecting mechanical working and heat treatment time and heat treatment temperature conditions of the feed steel or a product made from the feed steel to provide required mechanical properties for the product and carrying out mechanical working and heat treating steps and maintaining or increasing ductility and maintaining or increasing the yield stress of the steel and producing the product with the required mechanical properties.

19. A mechanically worked and heat treated steel product made by the method defined in any one of the preceding claims.

20. The steel product defined in claim 19 includes any one of wire, rod, bar, or strip.

21. The steel product defined in claim 20 includes a steel product that is made from any one of wire, rod, bar, and strip.