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(54) **Method and device for production of heat treated welded rail for rail transport and rail produced therewith**

(57) The present invention relates to a method and device for the production of heat treated welded rail for rail transport, such as railways and tramways. The invention also relates to a rail produced with the method and/or the device.

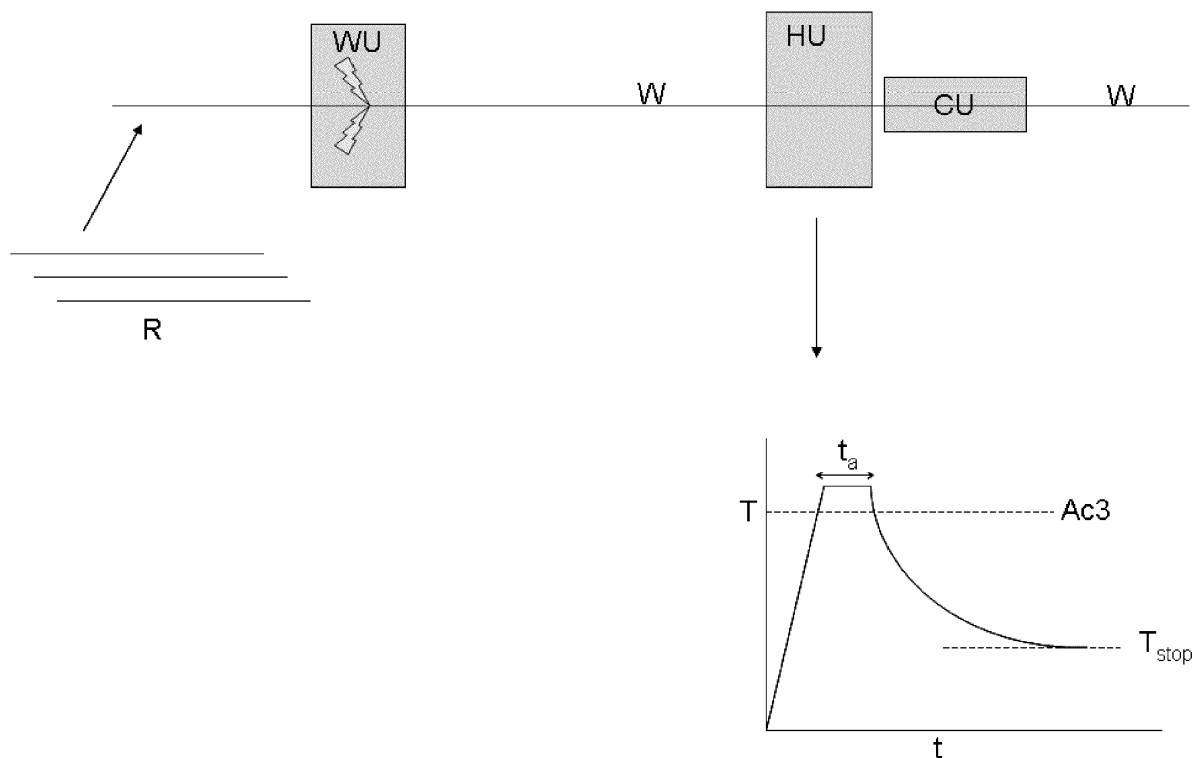


FIGURE 4

Description

Field of the invention

[0001] The present invention relates to a method and device for the production of heat treated welded rail for rail transport, such as railways and tramways.

[0002] The invention also relates to a rail produced with the method and/or the device.

Technological background and prior art

[0003] Traditionally, short lengths of rails were produced and used to build railways. These short lengths of (e.g.) 12 m were connected by means of fishplates leaving some space in between to absorb thermal expansion and contraction.

[0004] Nowadays, the lengths of rail are usually welded together on the track laying site to form continuous welded rail (CWR). In this form of track, the rails are usually welded together by (e.g.) flash butt welding (FBW) or Alumino-Thermic Welding (ATW) to form one continuous rail that may be several kilometres long, or to repair or splice together existing CWR segments. This form of track gives a smooth ride and needs less maintenance. Train speeds, axle loads and total tonnages carried have increased accordingly. Welded rails are more expensive to lay than jointed tracks, but have much lower maintenance costs.

[0005] FBW is currently the preferred process for joining together the as-manufactured rails and involves electrical resistance heating of the two rail ends, after which the two rail ends are butted together. This is generally carried out off-site, either at the rail-manufacturing plant or in a 'stand-alone' depot. The resulting welded 'strings' are FBW'ed or ATW'ed welded into track. ATW is essentially a manual process requiring a reaction crucible and a weld portion consisting of aluminium and iron oxide powders which together with suitable alloying additions and an exothermic reaction ultimately form a cast welded joint. There is no theoretical limit to how long a welded rail can be.

[0006] If not restrained, rails would lengthen in hot weather and shrink in cold weather. To provide this restraint, the rail is prevented from moving in relation to the sleeper by use of clips or anchors. Anchors are more common for wooden sleepers, whereas most concrete or steel sleepers are fastened to the rail by special clips which resist movement of the rail.

[0007] To produce CWR it is advantageous to use long lengths of rail to reduce the number of welds that have to be made. Welds are generally regarded as weak points in the finished long welded rail. To produce rails with the required mechanical properties like hardness, strength and fatigue properties, rails are increasingly being subjected to a heat treatment prior to being delivered to the customers. However, when welding these heat-treated rails together, as with any welding operation, the influ-

ence of the heat from welding results in a heat affected zone within which the properties of the original heat treated rail are changed. Depending on the precise welding conditions and steel composition, the hardness of the critical HAZ around the weld (i.e. that portion which fully re-austenitises during the pre-heating stage) is often higher than the parent rail as a result of the faster cooling rate experienced following welding than by the as-rolled rail. In the case of heat treated rail, the welding operation generally results in a lower hardness and loss of tensile strength in the critical HAZ as the weld cools more slowly than the original rail did during the rail heat treatment operation. In both cases, however, those parts of the rail adjacent to the critical HAZ have seen elevated temperatures below those required to re-austenitise the steel. These areas instead undergo spheroidisation of the pearlite resulting in significantly lower hardness than both the parent rail and the hard critical HAZs. Importantly, the resulting non-uniform hardness profile across a weld can lead to localised preferential wear in the soft zones and ultimately 'cupping' of the welds. Welds also produce variations in residual stresses or stress patterns along the length of the rail. For rails having a bainitic microstructure the welding process may result in a local destruction of the bainitic microstructure.

[0008] Another problem with the method as described hereinabove is that the length of the rail has to be as long as possible to reduce the welding costs and number of welds, but that transportation of these long lengths causes logistical problems when supplying to locations which do not have access to an infrastructure capable of handling long lengths, or to where it is not possible or economical to transport long lengths of rail.

[0009] CN1648263 discloses a method and device to produce long rails by welding together shorter lengths of steel and heat treating each individual weld in situ at the installation site by using oxy-acetylene burners to raise the weld to a temperature of about 900°C and thereafter cooling it using water or mist to a temperature below about 400°C. However, applying such a procedure at the installation site is fraught with potential practical problems, with the added disadvantage of inconsistent residual stresses and/or variations in microstructure remaining along the length of the rail.

Aims of the invention

[0010] The present invention aims to provide a method for producing rail of 'infinite' length with homogeneous properties along the entire length.

[0011] The invention also aims to obtain a rail of 'infinite' length with homogeneous properties along the entire length.

[0012] The present invention aims to provide a method for producing a heat treated rail of 'infinite' length with homogeneous properties along the entire length, and the rail produced therewith.

[0013] The invention also aims at providing a low-cost

method for producing rail of 'infinite' length with homogeneous properties along the entire length from short lengths of rail. Within the context of this invention the term "rail" is not meant to mean railway parts such as switches, crossings and the like.

[0014] 'Infinite' is intended to mean that as many lengths of rails can be welded together into a CWR as needed and that there is no theoretical limit to the number of lengths, only a practical limit.

Summary of the invention

[0015] A first aspect of the present invention is related to a method for the production of heat treated welded rail for rail transport comprising the subsequent steps of:

- i. providing rail lengths to the desired specifications (e.g. length, profile, properties, composition, etc);
- ii. welding two rail lengths together in a welding unit to produce a continuous welded rail (CWR), or producing a longer CWR by welding one or more additional rail lengths to the CWR;
- iii. optionally removing the weld upset or upsets, or parts thereof, for example by stripping, grinding, milling or any combination thereof,
- iv. post-welding heat treating the CWR in a heat treatment unit by heating the CWR, or by heating successive cross-sections of the CWR, to above the A_{c3} -temperature to achieve a fully austenitic microstructure in the CWR or in the successive cross-sections of the CWR, followed by holding the CWR or the successive cross-sections of the CWR at a holding temperature above A_{c3} for a prescribed time t_a followed by subjecting the CWR or the successive cross-sections of the CWR to cooling at a cooling rate using a cooling medium to a cooling stop temperature T_{stop} to achieve the desired transformed final microstructure in the CWR or in the successive cross-sections of the CWR thereby achieving the desired transformed final microstructure and properties along the entire length of the post-welding heat treated CWR;
- v. optionally providing the head of the post-welding heat treated CWR at the locations of a weld with the desired rail head profile, e.g. by grinding or milling.

[0016] By achieving the desired transformed final microstructure and properties along the entire length of the heat treated CWR it is meant that there are as little differences as possible over the length of the heat treated CWR. The disturbing influence of the welding together of two rail lengths is "ironed" out by the post-welding heat treatment, whereas the conventional pre-welding heat treatment still burdens the CWR with the variations in microstructure and properties as a result of the presence of the heat-affected zones caused by the welding process.

[0017] The major difference between the method ac-

cording to the invention and the state of the art is that it is a post-welding heat treatment, and not a pre-welding heat treatment as in the state of the art.

[0018] In an embodiment t_a is at least 1 minute and/or at most 10 minutes. Preferably t_a is at most 5 minutes. A_{c3} depends largely on the chemistry of the rail and the heating conditions, and can be easily determined by e.g. dilatometry. Preferably the holding temperature does not exceed 1000 °C. Preferably, the combination of holding temperature and holding time is chosen such that the CWR or the subsequent cross-sections of the CWR attain a fully austenitic microstructure with a small grain size, and therefore the holding temperature should be as low as possible (but above A_{c3}) and the holding time as short as possible. After the austenitisation the cooling rate, cooling stop temperature and cooling medium is chosen so as to obtain a homogeneous microstructure with low internal stress. Preferably the cooling from the austenite region is performed by accelerated cooling, e.g. at a rate of 1 to 50 °C/s, preferably at most 20 °C/s, more preferably at most 10 °C/s. Upon reaching the desired cooling stop temperature the remainder of the cooling to ambient temperature is preferably performed by still air (=unaccelerated) cooling.

[0019] CN1648263 discloses a method and device to produce long rails by welding together shorter lengths of steel and heat treating the individual welds in situ at the installation site by using oxy-acetylene burners to raise the weld to a temperature of about 900°C. The most important disadvantage is that only the individual welds are subjected to the prescribed heat treatment, rather than the entire rail including the welds as per our invention. The relatively localised reheating at the location of each weld of CN1648263 leads to another HAZ at the interface between that portion of the rail or weld that has been heat treated and the adjacent un-heat treated part. Furthermore, even when using the method from CN1648263, the number of welds needs to be minimized, because each weld and each heat treatment of such a weld adds to the overall cost and time taken to produce the final long length of welded rail.

[0020] The advantage of a rail produced by the method according to the invention is that the entire CWR (i.e. multiple lengths of rail welded together) has undergone the heat treatment in-situ, preferably close to where the rail is to be installed. The mechanical properties of weld and rail can therefore be produced near the installation site after the welding has taken place and importantly there are no HAZs introduced by localised heat treatment of individual welds as the entire welded rail length containing multiple welds is subjected to a single continuous heat treatment involving reheating and subsequent cooling. This has significant beneficial effects. Most importantly, the mechanical properties of the weld and the body of the rail are practically identical (the only possible exception being the very narrow fusion line itself). All previous traces of the individual welds are eradicated by the post-weld heat treatment. Furthermore, the residual

stresses in the CWR produced according to the invention will be the same at all locations along the length of the rail. By using the prescribed method, relatively short lengths (but still as long as possible to reduce the number of welds) of rail can be used, which enables/facilitates transport, e.g., free in the hold or in ISO standardized containers by sea and/or on lorries. Using short rail allows simplified logistics for rail transportation by road/rail or sea. In this way, the method according to the invention removes the need for major capital expenditure in locations without a local rail producer or without a local rail producer capable of supplying long length rails.

[0021] If the heat treatment facility is long enough to batch anneal a certain length of CWR, then the method according to the invention can be performed in batch mode. However, it is preferable to perform the heat treatment in a continuous heat treatment facility through which the CWR is fed at a certain feed rate so that the heat treatment occurs on a limited portion of the CWR at any given time. In a continuous heat treating facility each cross-section of the CWR successively undergoes the same thermal treatment as the rail is being fed through the heat treating facility at a chosen (preferably constant) feed rate. A heat treating facility as described in EP0765942-A1 would be suitable for this continuous heat treating process. Such a continuous heat treatment facility could e.g. be an induction heating unit or a set of induction heating units. In that case the continuous welded rail would be heat treated by feeding the rail through a (set of) heat treatment unit(s) and heat treat the rail by heating a cross-section of the rail to above the A_{c3} -temperature to achieve a fully austenitic microstructure in the rail section, followed by holding the rail section above A_{c3} for a prescribed time t_a followed by subjecting parts of the rail to cooling at a cooling rate using a cooling medium to a prescribed cooling stop temperature T_{stop} to achieve the desired homogeneous, transformed final microstructure at the selected parts of the rail along the entire length of the heat treated continuous welded rail. In the batch mode the entire rail undergoes the same heat treatment at the same time. So the length of the furnace is at least as long as the longest CWR treatable in this furnace. In continuous mode each cross-section of the rail undergoes the same heat treatment, but not at the same time. These continuous facilities can therefore be much shorter than the CWR, and are not limited to treating certain lengths of CWR.

[0022] Although it is preferable to perform the continuous heat treatment by heating the entire rail (batch mode) or the every cross-section (continuous mode) to above A_{c3} , it is also possible to e.g. only heat the head, or the head and the web, or the foot to above A_{c3} . However, this may result in variations in internal stresses over the cross-section, and this may be undesirable.

[0023] It is possible to weld together a plurality of rail lengths with a welding unit to create a CWR consisting of said plurality of rail lengths welded together (e.g. 10 rails of 12 m welded together to produce a 120 m long

welded rail), thereby emulating the capability to produce long lengths on a site where no facilities are available to produce these long lengths by rolling, and then subsequently feed this long length rail, consisting of said plurality of rail lengths welded together, into a heat treating unit to heat treat every part of the rail including the welds, and not only the welds. This will result in a CWR of consistent quality, microstructure and properties. So although the method can be used to produce CWR of very long lengths, it is also possible to cut the CWR after a certain length has been obtained if the cut CWR has to be transported. The long lengths thus produced may be welded together on the track laying site by conventional means, such as FBW or ATW. By using the method according to the invention the length of the continuous welded and heat-treated rail is theoretically unlimited, and only limited by practical issues such as transportation of the rail to the installation location.

[0024] In a preferable embodiment of the invention the feed rate for the heat treating step is between at least $0.5 \text{ m} \cdot \text{min}^{-1}$ and/or at most $10 \text{ m} \cdot \text{min}^{-1}$. Preferably the feed rate is at least $1 \text{ m} \cdot \text{min}^{-1}$ and/or at most 7 and more preferably at most $5 \text{ m} \cdot \text{min}^{-1}$. Ideally, the feed rate is between 2 and $4 \text{ m} \cdot \text{min}^{-1}$. Preferably the feed rate is a constant feed rate, because this is the best guarantee for a consistent quality of the heat treated rail.

[0025] The invention is embodied in a method wherein the weld upset/(s) is/(are) removed from the foot, preferably wherein the weld upset is removed from the foot, web and head of the CWR. Although the method according to the invention does not require removal of the weld upset, it is preferable to remove the so-called foot strip for heat treatment and performance purposes. The weld upset on the web and head of the CWR can be left, but it can also be removed to improve the aesthetic performance. Moreover it may act as an undesired "heating raiser". By removing the weld upset from the foot, or from the foot, web and head of the CWR, the quality of the CWR is improved, both aesthetically and mechanically because the smooth surface will not give to stress raisers, and the subsequent heat treatment is more homogeneous.

[0026] The CWR may be straightened and/or profiled after welding and before the post-welding heat treatment. It is also possible to straightened and/or profiled after the post-welding heat treatment.

[0027] In a preferable embodiment the heat treating step preferably utilises compressed air or air-mist cooling to cool down the heat treated CWR.

[0028] In a preferable embodiment of the invention the CWR is produced by welding together lengths of steel having a composition suitable for obtaining a pearlite microstructure after post-welding heat treatment, wherein the cooling stop temperature is below A_{r1} , and wherein the transformed final microstructure of the heat treated CWR is fully pearlitic and free of martensite or bainite phases. Pearlitic rails are the most commonly used type in the rail industry including the hypereutectoid rail steels

containing a vast majority of pearlite. When welding together these pearlitic (hypoeutectoid, eutectoid or hyper-eutectoid) steels, a large HAZ is produced, and the method according to the invention is particularly suited to produce a long rail from shorter rails without these large HAZs which is otherwise only possible by producing long lengths of rails as one single piece. The welding together of the rail followed by the heat treatment of the entire rail produces a rail which has the favourable properties of a heat treated rail and no HAZs that adversely affect the properties. Instead the rail has favourable heat treated properties over the entire length and no HAZs whatsoever. In order to obtain this it is important that the heat treatment is designed in such a way that the austenitic structure is cooled down at a rate which is high enough to produce a very fine pearlitic structure but which is not so high so as to run the risk of formation of bainite or martensite, and to a temperature sufficiently low to promote the pearlite formation. The cooling rate from the austenite range has to be high enough to prevent the ferrite nose (if at all present) in the CCT-diagram. This technology is readily available to the skilled person and thus commonly known. Subjecting samples of the composition, such as an R260, to tests like dilatometry will readily yield the required information about Ar₁ and Ac₃, and therefore about the annealing temperatures to achieve an austenitic microstructure in the rail and about the cooling rates required to obtain the desired final microstructure in the rail. The method is applicable to all hypo-, hyper- or eutectoid pearlitic rail grades.

[0029] In a preferable embodiment of the invention the CWR is produced by welding together lengths of steel having a composition suitable for achieving a bainite microstructure after heat treatment, wherein the cooling stop temperature is below the bainite finish temperature (B_f), and wherein the transformed final microstructure of the heat treated CWR is fully bainitic and substantially or preferably completely free of martensite and substantially or preferably completely free of pearlite or ferrite phases. There are different families of bainitic rails. Some are high strength rails offering good wear resistance and used primarily for heavy haul track while others have been designed specifically to address rolling contact fatigue in mixed traffic lines. By welding together these steels the resulting properties within the weld and HAZs can change from those of the as-manufactured rails. The method according to the invention is particularly suited to prevent this without the need to produce long lengths of rails as one single piece. The welding together of the rail lengths followed by heat treatment of the entire rail produced a rail which has the favourable properties of a heat treated rail but no welds at whose locations the favourable heat treated properties are destroyed. Instead the rail has favourable heat treated properties over the entire length and no HAZs whatsoever. In order to obtain this it is important that the heat treatment is designed in such a way that the austenitic structure is cooled through a temperature against time curve that produces the de-

sired microstructure. This technology is readily available to the skilled person and thus commonly known. Subjecting samples of the composition, such as an B320, to tests like dilatometry will readily yield the required information about Ar₁ and Ac₃, and therefore about the annealing temperatures to achieve an austenitic microstructure in the rail and about the cooling rates required to obtain the desired final microstructure in the rail. The method is applicable to all bainitic rail grades.

[0030] The welding is preferably of a type that generates a weld from only parent material, i.e. no filler material is used. These welding types encompass gas pressure welding, friction welding, electron beam welding. In a preferable embodiment the welding process is a flash-butt welding process.

[0031] In an embodiment of the invention the welding of the rail lengths to form a CWR or the welding of a rail length to a CWR is performed in a controlled atmosphere to avoid the decarburisation of the steels at the fusion line.

[0032] Straightening after or before welding the rail lengths together could be performed by pressing. It is preferable to profile the welded rail, e.g. by grinding, after the straightening.

[0033] A second aspect of the present invention is related to a device for performing the method according to the invention provided with:

- i. a welding unit for welding two rail lengths together to produce a CWR, or to produce a longer CWR by welding additional rail lengths to the CWR;
- ii. an optional unit for removing part of, or the whole weld upset or weld upsets, e.g. a stripping, grinding or milling or a combination thereof,
- iii. a heat treating unit

- for post-welding heat treating the CWR by subjecting the whole CWR to substantially the same heat treatment above the Ac₃-temperature to achieve a fully austenitic microstructure in the CWR in a batch heat treating unit, or
- for post-welding heat treating the CWR by feeding the CWR through the heat treatment unit for heating successive cross-sections of the CWR to above the Ac₃-temperature to achieve a fully austenitic microstructure in the successive cross-sections,

iv. a holding unit for holding the CWR or the successive cross-sections of the CWR above Ac₃ for a time t_a, said holding unit being optionally integrated in the heat treating unit,

v. a cooling unit for cooling parts of the CWR or the successive cross-sections of the CWR (head, base of the foot, web) or the entire CWR or the successive cross-sections of the CWR using a cooling medium to a cooling stop temperature T_{stop} to achieve the desired transformed final microstructure and properties in the post-welding heat treated CWR along

the length of the CWR,

vi. optional head profiling means for providing the head of the CWR at the locations of the weld or welds with the desired rail head profile,

vii. optional straightening means for straightening the CWR and/or optional straightening means to straighten the welded and heat treated CWR.

[0034] In a preferable embodiment of the invention the heat treatment unit and its ancillary devices (such as welding and grinding unit) is designed and constructed in such a way that it is relatively easy to construct at a given site, and that it is also relatively easy to deconstruct and relocate to a different site where rail is to be heat treated.

[0035] In an embodiment of the invention the welding unit contains means to perform the welding in a controlled atmosphere to avoid the decarburisation of the rails at the fusion line.

[0036] In a third aspect of the invention a post-welding heat treated CWR produced according to the method of the invention or produced using the device according to the invention is provided. In an embodiment the post-welding heat treated CWR comprises no heat affected zones at any position along the entire length of the heat treated continuous welded rail. It is preferable that the difference between the minimum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 10%, preferably 7.5%, more preferably 5% of the average hardness value of the post-welding heat treated CWR (HV30). It is preferable that the difference between the maximum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 15%, preferably lower than 10%, more preferably 7.5%, even more preferably 5% of the average hardness value of the post-welding heat treated CWR (HV30). It is preferable that the difference between the minimum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 10%, preferably 7.5%, more preferably 5% of the average hardness value of the post-welding heat treated CWR (HV30) and the difference between the maximum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 15%, preferably lower than 10%, more preferably 7.5%, even more preferably 5% of the average hardness value of the post-welding heat treated CWR (HV30). Figure 2 shows an average hardness value in HV30 indicated by "Mean P" in the figure. Note that the value at the fusion line is ignored in this respect as per the relevant standard. In a pre-welding heat treated pearlitic rail the minimum hardness is usually caused by spheroidisation of the pearlite in the HAZ.

[0037] The invention will now be further explained by means of a non-limitative example and figures. Five short lengths rails of not-yet heat treated R350HT (i.e. having

a composition comparable to R260) were provided which were flash-butt welded together in air using a welding program suitable for flash-butt welding. Each flash-butt welding device is different and no standardised set of operating parameters is available, but it is well within the scope of the skilled person to come up with a suitable welding programme for any standardized composition and it is not an undue burden to come up with such a welding programme. Reference is made to WO 2005/001204-A1 by way of example for R220 grades. Four welds were thus produced. Of these, two were subjected to a standard grind of the head (1 & 2) as per the standard FBW preparation procedure (BS EN14587-1:2007) as well as the base of the foot for easier handling, and two were subjected to a standard grind of the head and the base and upper part of the foot (3 & 4). The CWR thus produced was processed through an induction heat treatment plant by austenitising each cross-section of the CWR and cooling it after each cross-section was held above A_{c3} and subsequently cooled by means of accelerated cooling to T_{stop} . Cooling to ambient temperature was performed in still air. An example of a suitable heat treatment plant and details of the heat treatment of the samples is given in EP0765942-A1, the contents of which are herewith included herein by reference.

[0038] The material was subsequently examined metallurgically in accordance with BS EN14587-1:2007. This included the assessment of the Heat Affected Zone (HAZ) width, microstructure and rail hardness using the criteria specified for grade R350HT rail. It was concluded that heat treatment of the rail / weld combinations did not affect the results of the three-point bend test conducted on the flash butt welds. Microstructural evaluation of the heat treated weld revealed that the microstructure was extremely homogeneous and consistent with the measured hardness values. The microstructure is shown in figure 1a-d where the microstructure is shown for the fusion line (a), 4 mm from the fusion line (b), 8 mm from the fusion line (c) and 20 mm from the fusion line (d). The latter can be considered to be the heat treated parent material. Hardness values are presented in figure 2. With the exception of the fusion line, the material is completely pearlitic, and no evidence of martensite or bainite was observed. In figure 3 these hardness values are compared to the non heat treated welds (which are obviously lower and at the R260 level). The fusion line, where some ferrite is present, is so narrow that it does not affect the performance of the welded rail. But the main difference is the wide range in hardness values and the width of the HAZ of about 30 mm in comparison to the width of about 15 mm for the heat treated variant where, moreover, the increase in hardness is relatively marginal (15 HV30 on a level of 344 HV30 (<4.3%)) in comparison to the increase in hardness for the non heat-treated version (60 HV30 on a level of 260 HV30 >20%). Note that according to BS EN14587-1:2007 the hardness value at the fusion line is ignored when deciding whether or not the requirements for a certain grade are met. In figure 2 the minimum

and maximum value for R350HT rail (325 and 410 HV30) are presented along with the average P of the parent rail. Hardness was measured using a calibrated hardness tester HTM4225 at the depth of 5 mm below the running surface and with an indent interval of 2 mm at 30 kg load.

Brief description of the drawings

[0039]

Figure 1a-d shows the microstructure of the heat treated welded rail of the example above at the fusion line (a) and 4 (b), 8 (c) and 20 (d) mm from the fusion line.

Figure 2 is the hardness profile of the microstructure of figure 1. It is clearly visible that the hardness profile is very flat, with only a lower value at the fusion line and a couple of higher values next to the fusion line. Figure 3 is the hardness profile of a post-welding heat treated rail (solid line) compared to a pre-welding heat treated rail (dashed line) as a function of the distance to the weld (0 being the fusion line). Comparison of these profiles shows a very big difference in the hardness profile near the weld leading to the conclusion that the post-welding heat treated rail has a much more even hardness distribution along the length of the rail.

Figure 4 is a schematic and non-limiting drawing of a device according to the invention wherein R represents an amount of rail lengths which are welded together in a welding unit (WU) to form a CWR and subsequently heat treated in a heating unit (HU) and cooled in a cooling unit (CU). The WU is drawn to be in-line with the HU in this figure, but most likely the WU and the HU are decoupled processes for practical reasons. A schematic temperature profile is given as well. The location of the welds is indicated schematically with a 'W'.

Figure 5 is a plot of residual stress values along the length of the welded rail from the weld to 250 mm from the weld, showing the longitudinal residual stress on the surface of the foot at the centre-line of the rail and the vertical residual stress on the surface of the web of the rail at the rail mid-web position. It is evident from this Figure that the residual stress in the rail produced according to the invention is much lower and more even than the one in the process where the weld is not heat treated, which is the state-of-the-art process as described in [0007]. In the Figure the solid lines represent the post-welding heat treated rail and the dashed lines represents the pre-welding heat treated rail. The triangles show the vertical residual stress (in MPa) of the web, and the diamonds show the longitudinal residual stress (in MPa) of the foot of the rail, all as a function of the distance (in mm) from the weld.

Claims

1. A method for the production of heat treated welded rail for rail transport comprising the subsequent steps of:
 - i. providing rail lengths to the desired specifications (e.g. length, profile, properties, composition, etc);
 - ii. welding two rail lengths together in a welding unit to produce a continuous welded rail, or producing a longer continuous welded rail by welding one or more additional rail lengths to the continuous welded rail;
 - iii. optionally removing the weld upset or upsets, or parts thereof, for example by stripping, grinding, milling or any combination thereof;
 - iv. post-welding heat treating the continuous welded rail in a heat treatment unit by heating the continuous welded rail, or by heating successive cross-sections of the continuous welded rail, to above the Ac₃-temperature to achieve a fully austenitic microstructure in the continuous welded rail or in the successive cross-sections of the continuous welded rail, followed by holding the continuous welded rail or the successive cross-sections of the continuous welded rail section above Ac₃ for a prescribed time t_a followed by subjecting the continuous welded rail or the successive cross-sections of the continuous welded rail to cooling at a cooling rate using a cooling medium to a prescribed cooling stop temperature T_{stop} to achieve the desired transformed final microstructure and properties along the entire length of the post-welding heat treated continuous welded rail;
 - v. optionally providing the head of the post-welding heat treated continuous welded rail at the locations of a weld with the desired rail head profile, e.g. by grinding or milling.
2. The method according to claim 1 wherein the continuous welded rail is heat treated at a constant feed rate of at least 0.5 and/or at most 10 m·min⁻¹.
3. The method according to any one of the preceding claims, wherein the weld upset is removed from the foot, preferably wherein the weld upset is removed from the foot, web and head of the rail.
4. The method according to any one of the preceding claims, wherein the continuous welded rail is produced by welding together lengths of steel having a composition suitable for obtaining a microstructure which is substantially eutectoid or hypereutectoid after heat treatment, wherein the cooling stop temperature is below Ar₁, and wherein the transformed final microstructure treated of the post-welding heat treat-

ed continuous welded rail consists substantially of pearlite or pearlite and cementite and substantially free or completely free of martensite and/or bainite phases.

5. The method according to any one of the preceding claims, wherein the continuous welded rail is made by welding together lengths of steel having a composition suitable for producing a bainitic microstructure after heat treatment, wherein the cooling stop temperature is such that the transformed final microstructure of the post-welding heat treated continuous welded rail is fully bainitic and substantially or entirely free of martensite and substantially or entirely free of pearlite or ferrite phases.

6. The method according to any one of the preceding claims, wherein the welding process is a flash-butt welding process.

7. A device for performing the method of any one of claims 1 to 6 provided with:

- i. a welding unit for welding two rail lengths together in a welding unit to produce a continuous welded rail, or to produce a longer continuous welded rail by welding additional rail lengths to the continuous welded rail;
- ii. an optional unit for removing part of, or the whole weld upset or weld upsets, e.g. a stripping, grinding or milling or a combination thereof,
- iii. a heat treating unit

- a. for post-welding heat treating the continuous welded rail by subjecting the whole continuous welded rail to substantially the same heat treatment above the Ac_3 -temperature to achieve a fully austenitic microstructure in the continuous welded rail in a batch heat treatment unit, or
- b. for post-welding heat treating the continuous welded rail by feeding the continuous welded rail through the heat treatment unit for heating successive cross-sections of the continuous welded rail to above the Ac_3 -temperature to achieve a fully austenitic microstructure in the successive cross-sections,

- iv. a holding unit for holding the continuous welded rail or the successive cross-sections above Ac_3 for a time t_a , said holding unit being optionally integrated in the heat treating unit,
- v. a cooling unit for cooling parts of the continuous welded rail (head, base of the foot, web) or the entire continuous welded rail or the successive cross-sections CWR using a cooling medium to a cooling stop temperature T_{stop} to

achieve the desired homogeneous transformed final microstructure and properties in the post-welding heat treated continuous welded rail,
vi. optional head profiling means for providing the head of the continuous welded rail at the locations of the weld or welds with the desired rail head profile,
vii. optional straightening means to straighten the continuous welded rail and/or optional straightening means to straighten the heat treated continuous welded rail.

8. A post-welding heat treated rail produced according to the method of claim 1 to 6 or produced using the device of claim 7.

9. A rail according to claim 8 **characterised in that** no heat affected zones are present at any position along the entire length of the post-welding heat treated rail.

10. A rail according to claim 8 or 9 wherein:

- the difference between the minimum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 10% of the average hardness value (HV30), or wherein
- the difference between the maximum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 15% of the average hardness value (HV30), or wherein
- that the difference between the minimum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 10% of the average hardness value (HV30) and the difference between the maximum hardness of the post-welding heat treated CWR and the average hardness of the post-welding heat treated CWR is lower than 15% of the average hardness value (HV30).

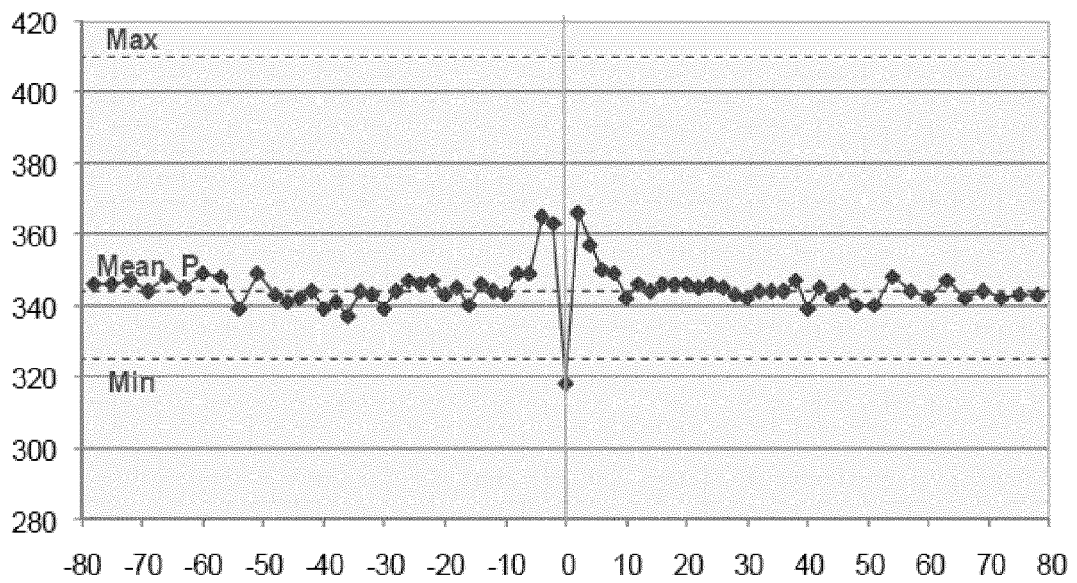


FIGURE 2

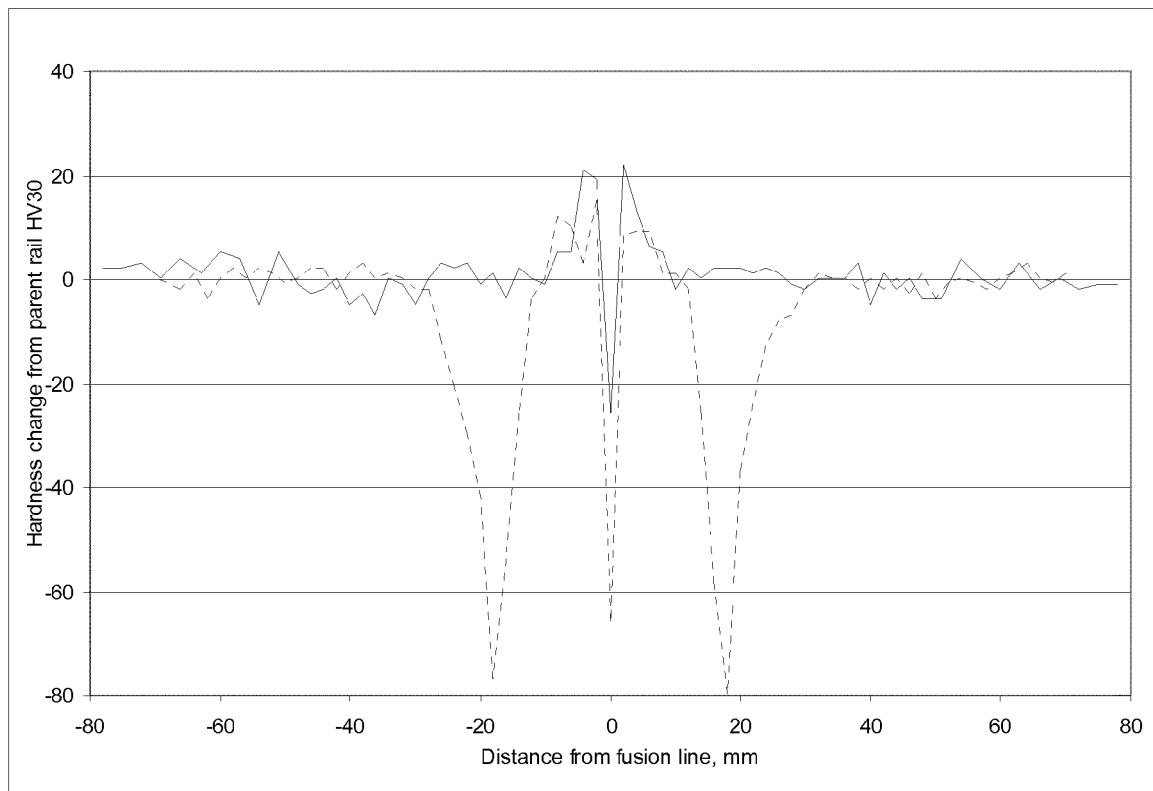


FIGURE 3

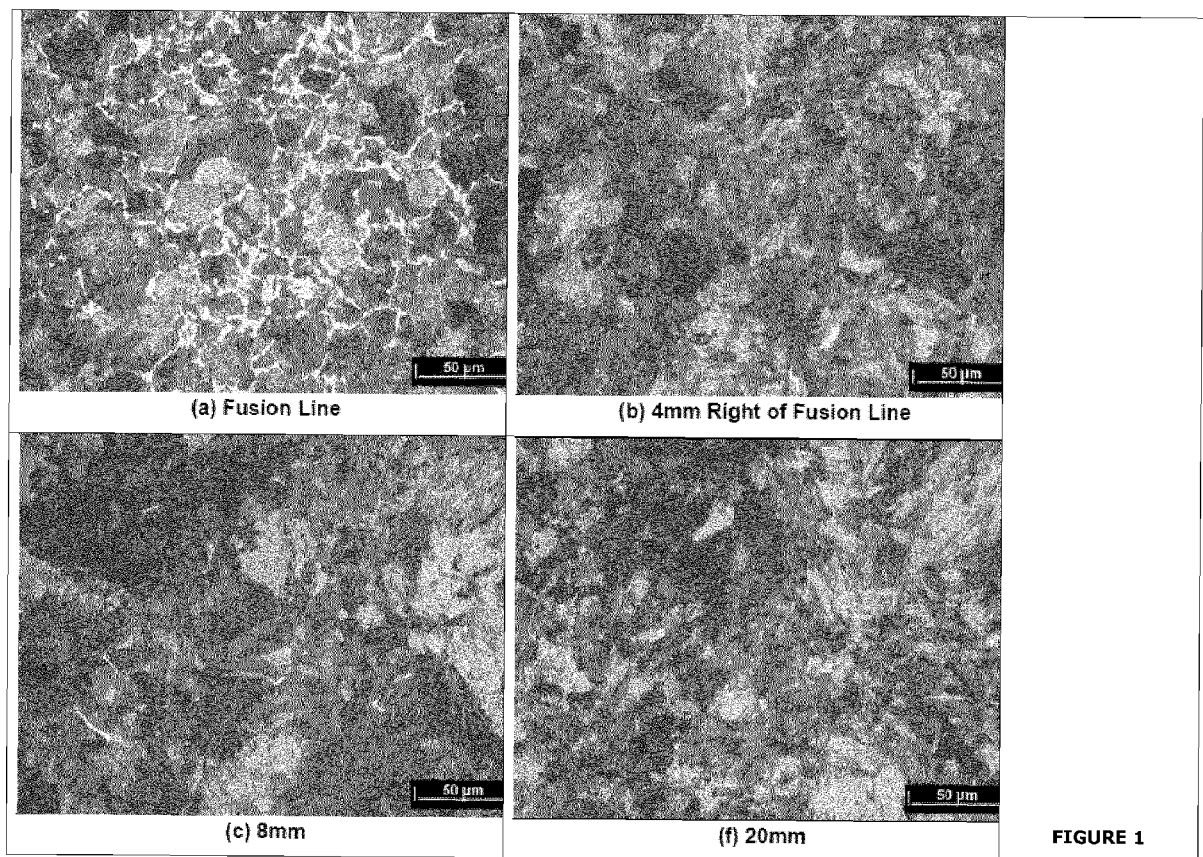


FIGURE 1

FIGURE 1

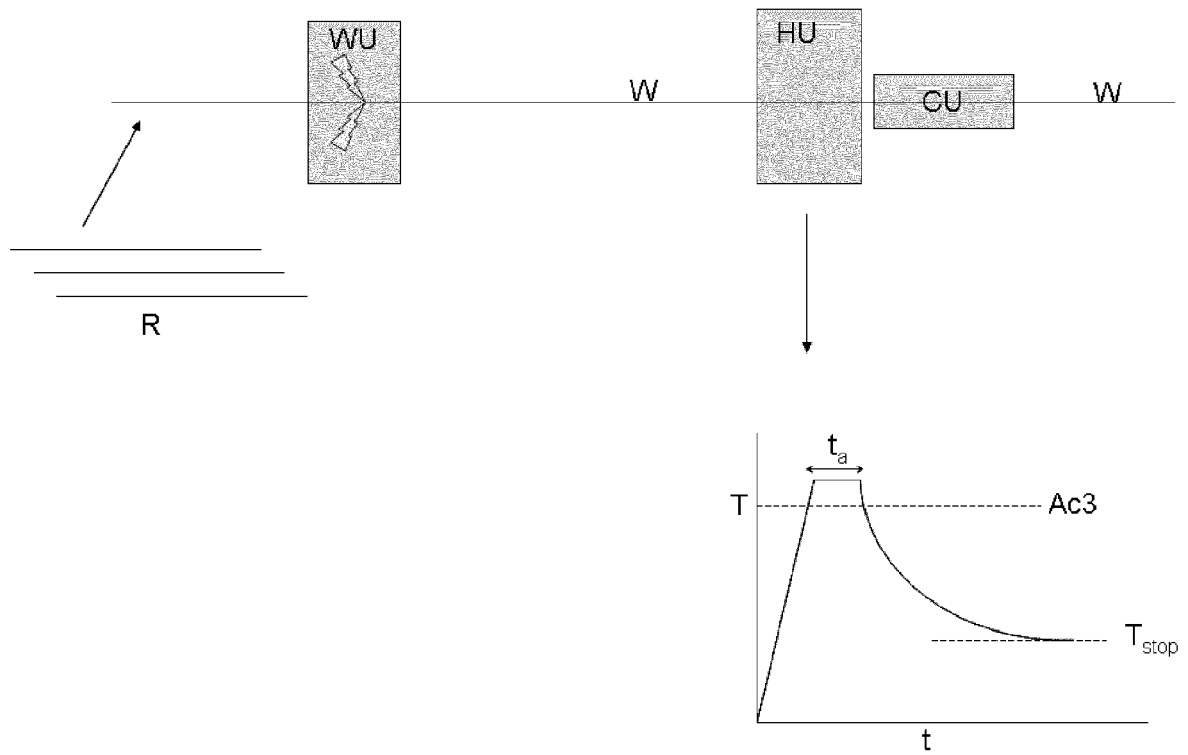


FIGURE 4

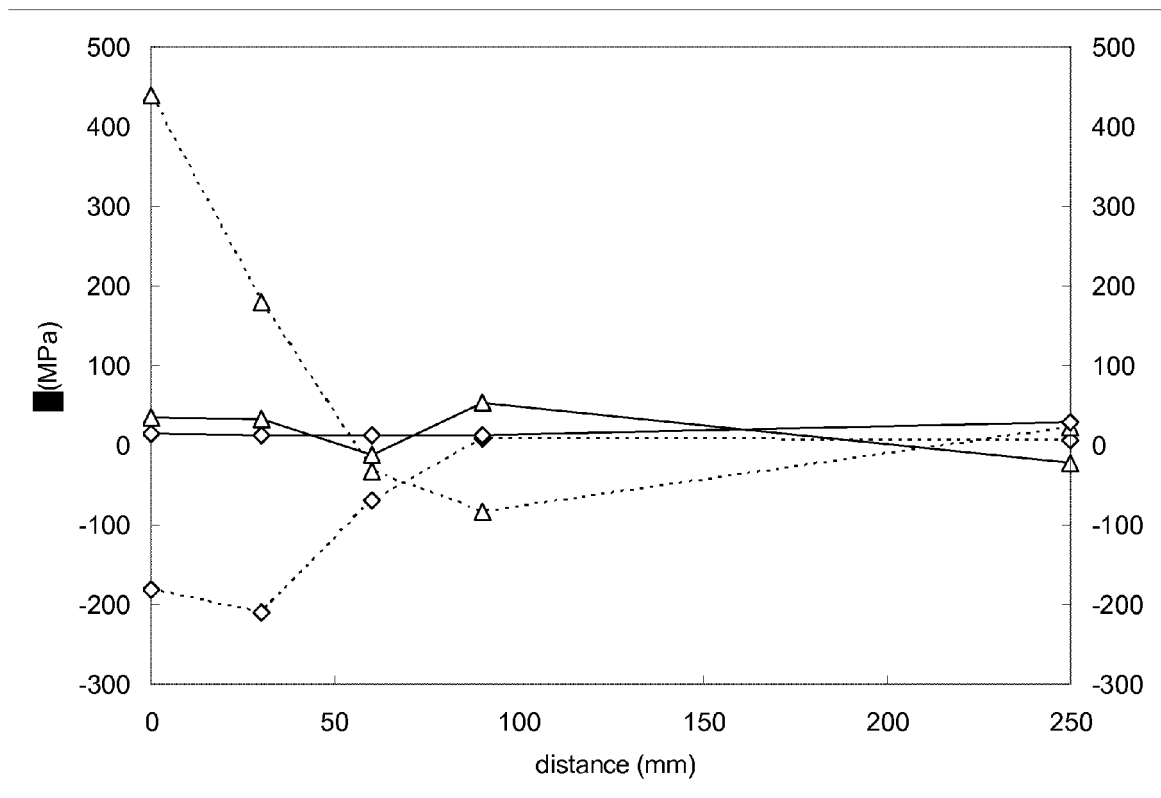


FIGURE 5



EUROPEAN SEARCH REPORT

Application Number
EP 14 18 6034

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2013/133784 A1 (KRISTAN JOSEPH VICTOR [US] ET AL) 30 May 2013 (2013-05-30) * paragraphs [0001], [0008], [0019] - paragraph [0022] * * paragraphs [0033], [0039] - paragraph [0042] *	1,4,6-9	INV. C21D9/04 C21D8/02 C21D1/18
A	----- CN 103 898 310 A (PANZHIHUA IRON & STEEL RES) 2 July 2014 (2014-07-02) * the whole document *	1-10	
A	----- US 2014/087320 A1 (KARIMINE KENICHI [JP] ET AL) 27 March 2014 (2014-03-27) * the whole document *	1-10	

			TECHNICAL FIELDS SEARCHED (IPC)
			C21D
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		26 January 2015	Huber, Gerrit
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 14 18 6034

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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26-01-2015

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013133784 A1	30-05-2013	CA 2857518 A1	06-06-2013
		CN 104145061 A	12-11-2014
		EP 2785917 A1	08-10-2014
		KR 20140105759 A	02-09-2014
		US 2013133784 A1	30-05-2013
		WO 2013081837 A1	06-06-2013

CN 103898310 A	02-07-2014	NONE	

US 2014087320 A1	27-03-2014	AU 2012259857 A1	21-11-2013
		CA 2836260 A1	29-11-2012
		JP 5549782 B2	16-07-2014
		US 2014087320 A1	27-03-2014
		WO 2012161207 A1	29-11-2012

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 1648263 [0009] [0019]
- EP 0765942 A1 [0021] [0037]
- WO 2005001204 A1 [0037]