There is disclosed a galvannealed steel strip product for hot press forming, comprising a strip of steel (1) made of hardenable steel alloy and plated with a galvannealed overlay coating (2) comprising an iron-zinc solid solution phase having a crystalline structure in which zinc is incorporated into a lattice of iron, and wherein the microstructure (3) of the steel (1) has an iron carbide structure consisting of spheroidized iron carbides (5, 6). The galvannealed steel strip product is manufactured by galvanizing a strip of steel (1) made of hardenable steel alloy with a zinc-based coating (2), coiling the galvanized steel strip, and annealing the coiled steel strip having the zinc or zinc alloy overlay in a batch furnace. The annealing time and temperature are set such that an average iron content of the annealed zinc-based coating is more than 15 wt-%, preferably more than 20 wt-%, most preferably more than 54 wt-%. The coiled steel strip may be annealed in an inert or reducing atmosphere to minimize the amount of oxides formed on the surface of the coating. There is also disclosed a method of manufacturing a hot-pressed steel component from the galvannealed steel strip product.
Description

METHOD OF MANUFACTURING A GALVANNEALED STEEL STRIP PRODUCT FOR HOT PRESS FORMING, METHOD OF MANUFACTURING A HOT-PRESSED STEEL COMPONENT, AND GALVANNEALED STEEL STRIP PRODUCT


Background of the Invention

Hot press forming is a well-established process to produce high-strength steel components in automotive industry. As a term, hot press forming has several synonyms such as hot stamping, hot forming in a press, or hot pressing. When metallurgical phase transformations are also considered, terms such as die quenching and press hardening are commonly used.

Most common practice is direct hot press forming, in which steel sheets are first austenitized at elevated temperatures and then shaped to steel components. In a hot press forming process including press hardening, sheets of steel made of hardenable steel alloy are first austenitized, then hot press formed and subsequently quenched with cooled press forming dies. Therefore the steel component gains its shape and mechanical properties in the same press.

Alternatively the steel sheet can be first cold-formed to a pre-shaped steel component in a first press, and subsequently the pre-shaped steel component is austenitized and hot press formed in a second press. The latter alternative is a so-called indirect hot press forming process in which most of the deformation is carried out in the cold-forming press.
In general, hot press forming provides for several advantages over cold press forming, for instance an improved formability of the steel material in the heated state and a reduced spring back effect, resulting in improved dimensional accuracy of the steel components. Also forming at high temperature requires smaller pressing force that results in better material utilization. In addition the steel component still includes some deformation capability even after press hardening.

However, hot press forming has also some disadvantages such as formation of an iron oxide layer on the surface of steel components during the heating process for hot press forming. The iron oxide layer must be removed by shot blasting or the like before painting or welding and thereby causes increase in costs. Also a bare steel surface can suffer from decarburization during heating that can result in loss of mechanical properties that is unacceptable. These drawbacks limited wider use of hot press forming in production of high-strength steel components.

Therefore, in recent years, in order to promote use of ultra-high strength press hardenable steel (PHS) in automotive industry, it has been found that steel sheets having a coating made of zinc, zinc alloy, Al-Si alloy or the like are suitable for hot press forming as they have the ability to protect the steel surface from decarburization and/or oxidation. Zinc-based coatings are highly preferred because they provide galvanic corrosion resistance in a corrosive damp environment. The process of applying a protective zinc coating to steel is known as galvanization. Examples of this process are hot-dip galvanization and electrogalvanization. In principle, the more zinc in the coating the better galvanic corrosion resistance performance. Therefore especially thick coatings including high amount of zinc (in terms of weight) are highly desired.

Annealing heat treatment after galvanizing process is a common process which increases the iron content of the galvanized coating. Such process is called galvannealing. In industrial scale, galvannealing is typically performed in a continuous process of a continuous galvanizing line which has limitations to produce thick galvannealed coatings, i.e.
thick galvannealed coatings having high enough average iron content. As the annealing is performed immediately after hot-dip galvanization including coating metal in a molten state, subsequent diffusion between the zinc and iron is dictated by molten state diffusion in which the main diffusion direction is from iron to zinc. Also typical galvannealed coatings of steel strip enable only a relatively slow heating rate for hot press forming because both the iron diffusion in the coating and the austenitization of steel material requires time.

EP 1 439 240 AI discloses a galvannealed steel material for hot press forming, which has a zinc or zinc alloy coating and an oxide film of zinc on the surface of the coating. The oxide film serves as a kind of oxide barrier layer which is said to prevent evaporation of molten zinc in the underlying coating at elevated temperatures connected to hot press forming process steps. The coating having the oxide barrier layer can be formed on a steel sheet by hot-dip galvanizing, followed for instance by annealing in an oxidizing atmosphere.

Further, annealing according to EP 1 439 240 AI in an oxidizing atmosphere means that the galvannealed steel sheet contains a thick oxide layer on the zinc surface prior to the heating process for hot press forming in a furnace. The heated sheet is transported under atmospheric conditions from the furnace to hot press forming equipment. This means that at least during this transportation phase, the oxide layer further increases. It is also an industrial practice that the heating furnace does not include protective gas and therefore the oxide increases also during the heating process for hot press forming. For these reasons, the resultant thick oxide layer on the coated steel component is a cumulative result of all of these steps causing oxidation and therefore the hot-pressed component in some cases needs oxide reducing after-treatment such as shot blasting. This is because such thick oxide layer hinders paintability and weldability of the galvannealed steel component. However different after-treatments, especially shot blasting, complicate the process and have difficulties to be performed for galvannealed steel components including complicated shapes. In addition removal of the
oxide layer removes also zinc metal which reduces the amount of zinc in the coating, which is disadvantageous with regard to corrosion resistance. Furthermore it has been found that this type of oxide film does not completely prevent the evaporation of zinc as the gas pressure under the oxide layer can damage the oxide layer. Therefore other approaches should be found.

EP 2 520 693 Al discloses a method of producing galvannealed steel sheet for hot press forming by performing the annealing of zinc-based plated steel sheet at a temperature region of 600-750°C for 1 - 30 minutes to obtain a steel blank which has a zinc oxide layer in its uppermost surface portion and below it a zinc-iron alloy phase having an Fe content of at least 25 mass %. In this reference, steel is annealed at rather high temperature and short time in a sheet form. In addition, it does not disclose a specific iron carbide structure.

US 2012/0118437 A1 discloses zinc or zinc alloy coated steel for hot forming having an inorganic overlay covering the zinc alloy coating to prevent loss of zinc during heating and hot forming. In one embodiment of this reference, batch annealing is performed for threading the inorganic overlay containing hexavalent chromium.

US 2012/0279868 A1 discloses a method for manufacturing a galvannealed and flexibly rolled steel strip, in which the steel strip is hot rolled and then cold rolled; the steel strip is subjected to an electrolytic galvanization; and after the electrolytic galvanization the steel strip is heat treated in a bell-type annealing furnace at temperatures of 250°C to 350°C for a period of 4 to 48 hours to produce a zinc/iron layer. However, there are unambiguous pointers that these flexibly rolled steel strips are intended for cold-forming applications because of the disclosure about high isotropic strength and recrystallization annealing of the steel strip. As can be understood and also explained in this description, the decisive strength of the hot press forming steel forms after, not before, the forming process. Therefore this publication does not disclose hot press forming steels that are made of hardenable steel alloy.
Summary of Invention

An object of the present invention is to provide a method of manufacturing a galvannealed steel strip product which can accelerate the manufacture of a hot-pressed steel component, a method of manufacturing the hot-pressed steel component from the galvannealed steel strip product, and a galvannealed steel strip product which is suitable for hot press forming.

A further aim is to provide a solution for hot press forming that provides improved galvanic corrosion protection performance to the products.

According to a first aspect of the present invention, there is provided a method of manufacturing a galvannealed steel strip product for hot press forming, comprising a step of galvanizing a strip of steel made of hardenable steel alloy with zinc or zinc alloy, a step of coiling the galvanized steel strip, and a step of annealing the coiled steel strip in a batch furnace. The annealing time and temperature are set such that the average iron content of the annealed coating is more than 15 wt-%, preferably more than 20 wt-%.

The steel strip is coiled and annealed as galvanized. In other words, there is not formed an additional top coating on the galvanized steel strip as suggested by US 2012/0118437 Al. Rather, the coating obtained by galvanizing the steel strip forms an overlay on the steel strip.

Herein, the term "annealing" refers to a heat treatment (galvannealing) performed after galvanization and prior to the beginning of the heating process for the hot press forming. Furthermore, the phrase "galvanizing the steel strip with zinc alloy" relates to galvanized zinc alloy coatings containing less than 5 wt-% of iron, typically less than 3 wt-% of iron. The zinc alloy coating may contain aluminum in a range 0.1 - 20 wt-% and optionally other alloying elements such as magnesium in a range 0.5 - 5 wt-%.

The steel strip is made of hardenable steel alloy. The hardenable steel alloy can be hardened by quenching after hot press forming to
increase the strength of the hot-pressed steel component. Most preferably the hardenable steel is press hardened, i.e. hardened by quenching immediately after hot press forming by forming tools/dies, because this avoids further zinc oxidation and simplifies the manufacture of components. In other words, the hardenable steel may be so-called press hardenable steel (PHS).

The batch furnace enables longer annealing times and solid state diffusion compared with a continuous annealing furnace. When the coiled steel strip is annealed in the batch furnace, diffusion between iron and zinc takes place and iron-zinc intermetallic phases are gradually formed, followed by gradual formation of an iron-zinc solid solution phase having a crystal structure in which zinc is incorporated into a lattice of iron. The higher iron content in the coating reduces the risk for cracking related problems and problematic evaporation of zinc, for instance. Therefore, according to the prior art, the iron-zinc intermetallic phases are transformed to the iron-zinc solid solution phase during heating process for hot press forming. That naturally requires time and therefore slows down the process. However if the iron-zinc intermetallic phases are transformed to the iron-zinc solid solution phase during annealing of the steel strip galvanized with zinc or zinc alloy and prior to being heated for hot press forming, the heating process for hot-press forming can be shortened. A quicker heating process for hot-press forming is an advantage as this means that the cycle times of the heating equipment and the press forming equipment can be brought more close to each other.

It goes without saying that it takes the more annealing time for increasing the average iron content in the coating the larger the coating weight or thickness of the galvanized coating is. If the average iron content of the annealed coating is not more than 15 wt-%, the heating process for hot-press forming is relatively long and it is difficult to be shortened as desired. The average iron content of the annealed coating is preferably more than 20 wt-% so that the heating process for hot-press forming can be further shortened.
As discussed above, the galvanized coating undergoes iron-zinc phase transformations during annealing. Since iron-zinc phase transformations are endothermic reactions that need heat energy, the annealed coating consumes less heat energy during the heating process for hot press forming as compared with a coating containing a lower iron content. In addition, a matt overlay of the annealed coating absorbs heat energy more efficiently as compared with an ordinary gloss surface of galvanized coating. For these reasons, the present invention enables also more efficient heating.

The galvanized steel strip may also be coiled and annealed by utilizing an open coil arrangement, which arrangement is known for example of US 3 281 290 A.

The formation of zinc oxide can be further reduced or even completely avoided if the coiled steel strip is annealed in an inert or reducing atmosphere. Therefore the role of oxides is optional. In the context of the present invention, the term "inert atmosphere" refers to a gaseous mixture that contains little or no oxygen and mostly consists of non-reactive gases or gases that have a high threshold before they react. On the other hand, the term "reducing atmosphere" means that the oxidation is prevented by removal of oxygen and other oxidizing gases or vapors, and which contains an actively reducing gas. The coating preferably comprises the iron-zinc solid solution phase, more preferably on the surface of galvannealed coating. As compared with the a-Fe phase of pure iron, the iron-zinc solid solution phase has a larger lattice constant. The presence of this phase can be ascertained for instance by combined use of an X-ray diffraction apparatus and an elemental analyzer such as EPMA (electron probe micro analyzer). The iron-zinc solid solution phase is less sensitive for melting than a pure zinc coating. This is because the melting point of iron-zinc solid solution phase is at least 782°C whereas the melting point of pure zinc is 420°C. The higher melting point of the iron-zinc solid solution phase inhibits the evaporation of molten zinc during the subsequent heating process for hot press forming so that less zinc is evaporated into the furnace.
Zinc oxide as suggested in EP 1 439 240 Al or any additional overlay as suggested by US 2012/0118437 Al is not necessarily needed as a barrier layer to prevent evaporation during hot press forming if the galvannealed coating of the steel strip comprises the iron-zinc solid solution phase which increases the melting point.

Together with the shortened heating process for hot press forming as described earlier, it is assumed that it is possible to reduce the overall amount of oxides on the surface of the coated hot-pressed steel component. The amount of oxides on the surface of the hot-pressed steel component may be even so low that the oxides do not necessarily need to be removed from the surface of the hot-pressed steel component before the hot-pressed steel component is painted or welded.

The lowered amounts of evaporated and oxidized zinc mean that the residual amount of effective zinc on the coated hot-pressed component can be increased in comparison to the prior art. In addition, thick galvannealed coatings are enabled. Therefore the present invention can provide a galvannealed steel strip that holds improved galvanic protection performance.

The annealing time and temperature are preferably set such that the annealed coating consists essentially of the iron-zinc solid solution phase. According to the Zn-Fe phase diagram, this means that the average iron content is more than 54 wt-%. If the annealed coating consists essentially of the iron-zinc solid solution phase, no iron-zinc intermetallic phase needs to be transformed to the iron-zinc solid solution phase during the heating process for hot press forming. The coating consisting essentially of the iron-zinc solid solution phase consumes less heat energy during the heating process for hot press forming as compared with a coating containing no or less iron-zinc solid solution phase. This also enables the accelerating of the manufacture of a hot-pressed steel component.

Since the batch furnace enables longer annealing times and solid state diffusion compared with a continuous furnace, it is possible to produce a thick galvannealed coating which has a coating weight of more
than 160 g/m², preferably more than 180 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc, by performing the annealing in a batch furnace. A high coating weight improves the galvanic corrosion resistance performance notably. Preferably, the hardenable steel alloy has the following composition:

- C: 0.08 - 0.45 wt-%
- Mn + Cr: 0.5 - 3.5 wt-%
- Si: < 1 wt-%
- Al: < 0.2 wt-%
- Ni: < 1.0 wt-%
- Cu: < 1.0wt-%
- B: < 0.01 wt-%
- Ti: < 0.2 wt-%
- Nb: < 0.2 wt-%
- Mo: < 1.0 wt-%
- V: < 0.5 wt-%
- Ca: < 0.01 wt-%,

the balance being iron and residual contents or unavoidable impurities.

Hardenable steel alloy may mean that quenching index $D_{\text{inch}}$ of the steel is equal or higher than 3 as calculated by the known equation available in ASTM A255-67. Here the effect of boron on such index can be taken into account by using an equation $fB = 1 + 2.7(0.85$-wt%$C)$. In addition, standardized grain size No. 6 may be used in the calculation. Furthermore, the annealing time and temperature are preferably set such that a microstructure of the steel having an iron carbide structure consisting of spheroidized iron carbides is obtained. Spheroidizing of iron carbides in the steel strip may improve cold-formability and more importantly, enable faster austenitization during heating process connected to hot press forming. During annealing in the batch furnace the iron carbides, such as Fe₃C, may first build up at the grain boundaries and then inside the grains.
In a batch furnace, the annealing temperature can increase very slowly because of the substantial mass of the steel coil. This avoids molten phases in the coating as the diffusion of iron has time to proceed and enables substantially solid state diffusion. Therefore the heating rate and the heating temperature of the annealing are set such that phase transformations that increase the iron content in the coating have time to proceed and molten iron-zinc phases are this way avoided. The annealing temperature is preferably raised very slowly or alternatively in stages to avoid molten phases at the outer periphery of the steel coil that heats up while the core of the steel coil is still cool.

According to a second aspect of the present invention, there is provided a method of manufacturing a hot-pressed steel component from a galvannealed steel strip product, comprising a step of manufacturing a galvannealed steel strip product according to the first aspect of the present invention, a step of blanking the galvannealed steel strip product and optionally cold press forming the blank to obtain a pre-shaped component, a step of heating the blank or pre-shaped component, and a step of hot press forming the heated blank or pre-shaped component.

As discussed above, the use of the galvannealed steel strip product which is manufactured according to the first aspect of the present invention may shorten the heating process for hot press forming by reducing the time needed for transforming the iron-zinc intermetallic phases to the iron-zinc solid solution phase. Furthermore, as discussed also above, due to the carbide structure of the galvannealed steel strip product which is manufactured according to the first aspect of the present invention, a quicker austenitization process included in the heating process for hot press forming may be realized. Therefore, both of the causes that currently lengthen the heating process for hot press forming can be improved by means of the present invention.

The hot press forming step is preferably started within 3 minutes, more preferably within 2 minutes calculated from starting of the heating step.
If, as described above, the amount of oxides formed on the surface of the galvannealed steel strip product is kept low during annealing and if the heating process for hot press forming is shortened, it is possible to reduce the overall amount of oxides to such an extent that the oxides, if any, do not need to be removed by shot blasting or the like before painting or welding. In this case, the hot-pressed steel component may be painted or welded without removing oxides from the surface of the galvannealed steel strip product or the surface of the hot-pressed steel component.

According to a third aspect of the present invention, there is provided a galvannealed steel strip product for hot press forming, comprising a strip of steel made of hardenable steel alloy which is plated with a galvannealed coating comprising an iron-zinc solid solution phase, said iron-zinc solid solution phase having a crystal structure in which zinc is incorporated into a lattice of iron and wherein the microstructure of the steel has an iron carbide structure consisting of spheroidized iron carbides.

The galvannealed steel strip product is obtainable by the method according to the first aspect of the present invention and thus includes a coiled steel strip. However, although the coil form is preferred, the coiled steel strip may also be cut to length before it is delivered to a site having hot press forming equipment. In the latter case, the galvannealed steel strip product has a sheet shape which sheet is cut from the annealed coil consisting of galvannealed steel strip.

As in the first aspect of the present invention, the galvannealed coating forms an overlay optionally having zinc oxide on the surface. In other words, there is not formed an additional top coating on the galvannealed coating as suggested by US 2012/0118437 A1, including phases other than Fe-Zn galvanneal phases and the optional zinc oxide.

As discussed above, the iron-zinc solid solution phase is less problematic than the iron-zinc intermetallic phases during hot press forming. The galvannealed steel strip product thus facilitates the manufacture of a hot-pressed steel component in this respect.
Furthermore, spheroidizing of iron carbides in the steel strip can improve cold-formability and enable faster austenitization.

As can be understood from above, the discussed zinc oxide is optional. Painting or welding of the hot-pressed steel component may be facilitated if the amount of zinc oxide on the surface of the galvannealed steel strip product, if present, is less than 10 mg/m², preferably less than 5 mg/m² per side of the steel strip, as converted to the weight of zinc. Such a low amount of zinc oxide can be obtained if the coiled steel strip has been annealed in an inert or reducing atmosphere.

The average iron content of the galvannealed coating should be more than 15 wt-%, preferably more than 20 wt-%. If the iron content of the coating is too low, there is the risk that the formation of the iron-zinc solid solution phase becomes inadequate and the heating process for hot press forming cannot be shortened as desired.

The galvannealed coating preferably consists essentially of the iron-zinc solid solution phase. According to the Zn-Fe phase diagram, this means that the average iron content is more than 54 wt-%. If the coating consists essentially of the iron-zinc solid solution phase, no iron-zinc intermetallic phase needs to be transformed to the iron-zinc solid solution phase during the heating process for hot press forming. Therefore, manufacture of the hot-pressed steel component can be further accelerated.

The coating may have a coating weight of more than 160 g/m², preferably more than 180 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc, to improve the galvanic corrosion resistance. Preferably, the hardenable steel alloy has the following composition:

C: 0.08 - 0.45 wt-%
Mn + Cr: 0.5 - 3.5 wt-%
Si: < 1 wt-%
Al: < 0.2 wt-%
Ni: < 1.0 wt-%
Cu: < 1.0wt-%
B: < 0.01 wt-%
Ti: < 0.2 wt-%
Nb: < 0.2 wt-%
Mo: < 1.0 wt-%
V: < 0.5 wt-%
Ca: < 0.01 wt-%,
the balance being iron and residual contents or unavoidable impurities.

Coating weight and compositional measurements of the galvannealed coating can be made through the thickness of the coating by a Glow Discharge Optical Emission Spectrometry (GD-OES) analysis or equivalent. However, weight of zinc can also be measured from the galvanized steel strip by the method comprising dissolving the coating and analyzing it by ICP (inductive coupling plasma) emission spectrometry.

To determine the zinc content of the oxidized layer formed during bell furnace annealing, the amount of zinc oxide is measured by dissolving the galvannealed coating with 5% iodine methyl alcohol solution, extracting the residue by fusing mixture, dissolving the residue with hydrochloric acid and finally analyzing that by ICP to determine the zinc amount and then calculating that as ZnO.

**Brief Description of Drawings**

Fig. 1 schematically shows an example of annealing a galvanized steel coil in a bell-type furnace.

Fig. 2 schematically illustrates an example of a galvannealed steel strip product for hot press forming and the microstructure thereof comprising spheroidized iron carbides formed at grain boundaries and inside the grains.

Figs. 3 and 4 show pictures of a microstructure having an iron carbide structure consisting of spheroidized iron carbides. The pictures are taken by optical microscope (Nital etching).
Brief Description of Reference Numbers
1 Steel
2 Galvannealed coating
3 Microstructure
4 Grain defined by grain boundaries
5 Iron carbide formed inside the grain
6 Iron carbide formed at the grain boundary

Preferred Embodiment

In the following, a preferred embodiment of the present invention is described in detail. In the preferred embodiment, the invention is applied to a steel strip made of hardenable steel alloy, and the galvannealed steel strip product obtained from the steel strip made of hardenable steel alloy is subjected to a hot press forming process, followed by quench hardening immediately after hot press forming by press forming dies. It is, however, to be understood that the invention is also useful for hot press forming without quench hardening.

A) Method of Manufacturing Galvannealed Steel Strip Product

The method of manufacturing the galvannealed steel strip product comprises the following steps:

a) providing a steel strip made of hardenable steel alloy;
b) galvanizing the steel strip with zinc or zinc alloy; and
c) coiling the galvanized steel strip and annealing the coiled steel strip having a zinc or zinc alloy overlay, in a batch furnace.

Steps a) to c) are now explained in more detail.

a) Providing Steel Strip

In step a), a steel strip made of hardenable steel alloy is provided.

The steel strip can be obtained for instance by hot rolling and subsequently pickling the hot-rolled steel strip. Optionally and additionally the hot-rolled and pickled steel strip can be cold-rolled to obtain a cold-rolled steel strip.
The steel strip includes alloying elements in an amount required for a desired amount of hardening (i.e. a desired amount of martensite transformation) so it is made of hardenable steel alloy. The needed alloying level for hardening is dependent for instance on cooling speed at quenching, hot forming degree and material thickness.

The hardenable steel alloy may, for example, have the following composition:

<table>
<thead>
<tr>
<th>Element</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.08 - 0.45 wt-%</td>
</tr>
<tr>
<td>Mn + Cr</td>
<td>0.5 - 3.5 wt-%</td>
</tr>
<tr>
<td>Si</td>
<td>&lt; 1 wt-%</td>
</tr>
<tr>
<td>Al</td>
<td>&lt; 0.2 wt-%</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt; 1.0 wt-%</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt; 1.0 wt-%</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 0.01 wt-%</td>
</tr>
<tr>
<td>Ti</td>
<td>&lt; 0.2 wt-%</td>
</tr>
<tr>
<td>Nb</td>
<td>&lt; 0.2 wt-%</td>
</tr>
<tr>
<td>Mo</td>
<td>&lt; 1.0 wt-%</td>
</tr>
<tr>
<td>V</td>
<td>&lt; 0.5 wt-%</td>
</tr>
<tr>
<td>Ca</td>
<td>&lt; 0.01 wt-%</td>
</tr>
</tbody>
</table>

The balance being iron and residual contents or unavoidable impurities.

Next the reasons for alloying are explained in short.

Carbon C is a basic element to increase hardenability of steel and it primarily determines the hardness and tensile strength of the steel after press-hardening. Therefore at least 0.08 wt-% carbon is preferred, more preferably the lower limit for carbon is 0.15 wt-%. However, if the carbon exceeds 0.45 wt%, the weldability will weaken too much. Therefore, the upper limit for carbon is preferably 0.3 wt-%. Further suitable amount of carbon enables the formation of proper size carbides during annealing.

Manganese Mn and Chromium Cr are also very efficient elements to increase hardenability and their sum is preferred to be in the range 0.5 - 3.5 wt-%. However too high contents of these alloying elements may
impair ductility and therefore the sum of Mn and Cr is more preferably in
the range 0.8 - 2.0 wt-%.

Silicon Si is also an element that increases hardenability. In
addition it can be utilized as deoxidation agent. However, it content is
preferred to be limited to less than 1 wt-% since too much silicon would
cause steel surface defects. Most preferably, silicon is alloyed in the
range 0.05 - 0.5 wt-%.

Aluminum Al can be alloyed up to 0.2 wt-%, but it is more
preferably alloyed in the range 0.01 - 0.06 wt-% to serve as deoxidation
agent.

Also Nickel Ni and Copper Cu can be utilized up to 1 wt-% for
increasing hardenability, but their contents are more preferably below 0.5
wt-% and below 0.2 wt-%, respectively, in order to avoid increase in
alloying costs.

Boron B is very effective element to increase hardenability with
relatively low alloying levels up to 0.01 wt-%. The hardenability is
advantageously solved by alloying boron in the range 0.0001 - 0.005
wt-%. In this case it is necessary to alloy also titanium Ti 0.01 - 0.1
wt-% to protect boron B from Nitrogen N by forming TiN. If Ti is alloyed
more than stoichiometric amount in relation to nitrogen (i.e. Ti > 3.4 N),
the excess titanium hinders coarsening of austenite grains during
austenitization by forming TiC. However, if boron is not alloyed, it is no
need to alloy titanium for this reason. Generally, it is allowed to alloy Ti
up to 0.2 wt-% to gain precipitation strengthening and/or grain refining
effects.

Niobium Nb can be alloyed up to 0.2 wt-%, but it is preferably
alloyed in the range 0.005 - 0.1 wt-%, even more preferably in the range
0.01 - 0.08 wt-% in order to control grain size during austenitization.
Niobium form nitrides, carbonitrides, and/or carbides which hinder
recrystallization and hinders coarsening of austenite grains.

Molybdenum Mo can be alloyed up to 1 wt-% to promote
martensite formation and raise recrystallization temperature. However,
since Mo is a relatively expensive alloying element, its content is more preferably limited to 0.2 wt-% or less.

Vanadium V can be alloyed up to 0.5 wt-% to increase hardenability. However, from the alloying costs point of view, V of 0.2 wt-% or less is preferred. Vanadium can also be utilized as microalloying element in a range of 0.01 - 0.1 wt-%.

Calcium Ca can be included up to 0.01 wt-% or 0.0001 - 0.005 wt-% in the steel due to a possible calcium treatment included in smelt processing.

Unavoidable impurities can be nitrogen N, phosphor P, sulfur S, oxygen O and rare earth metals (REM) or the like. Nitrogen N is an element that can bind microalloying elements existing in the steel to nitrides and carbonitrides so it can form precipitates. This is why a nitrogen content of at least 0.0005 wt-% can be included in the steel. However, more than 0.02 wt-% of nitrogen would allow nitrides to coarsen. Therefore, the nitrogen content should preferably be limited to 0.0005 - 0.02 wt-%. Phosphor P is usually unavoidably included in the steel and should be restricted to 0.06 wt-% since a higher content can be harmful for ductility. Most advantageously the upper limit for P is 0.02 wt-%. However, excessive lowering of P may be disadvantageous economically and therefore a lower limit of 0.005 wt-% may be applied. Sulfur S is usually unavoidably included in the steel and should be restricted to contents of less than 0.02 wt-%, preferably less than 0.01 wt-%. However, excessive desulfurization may be disadvantageous economically and therefore a lower limit of 0.0001 wt-% may be applied. Oxygen O may exist as an unavoidable element in the steel, but can be restricted to less than 0.005 wt-%, more preferably less than 0.002 wt-%. This is because as it may exist as inclusion that can debilitate mechanical properties.

b) Galvanization

In step b), the steel strip is galvanized with zinc or zinc alloy to provide a corrosion protection layer having galvanic protection
performance to the steel strip and most importantly, to the hot press formed steel component. Further galvanization protects the surface of the steel strip from decarburization and/or oxidation during heating involved in the hot press forming process.

Step b) may be carried out by electrogalvanization (EG) of the steel strip. The coating weight of the electrogalvanized steel strip may be 3 - 150 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc. In case of very thin zinc coatings, such as less than 10 g/m², the zinc does not provide comparable galvanic corrosion resistance, but only prevents iron to oxidize or form scale during hot press forming. Normally the coating weight should be not less than 100 g/m², preferably not less than 150 g/m² to guarantee a desired galvanic corrosion resistance after hot press forming.

Step b) is preferably carried out by hot-dip galvanization (HDG). Such a step is carried out by conveying the steel strip through a bath of molten zinc or zinc-alloy. Hot-dip galvanization is advantageous because it enables thick coating layers with excellent galvanic corrosion protection performance. The coating weight of the hot-dip galvanized steel strip may be 50 - 800 g/m², preferably 100 - 600 g/m² as measured from both sides of the steel strip, and as converted to the weight of zinc. Coating thicknesses of up to 1200 g/m² are obtainable if more than one step of hot-dip galvanization is performed. The coating weight is preferably more than 160 g/m², more preferably more than 180 g/m² to improve galvanic corrosion resistance over conventional galvannealed coatings. Steel components made of such a hot-dip galvanized steel strip are especially suitable for underbody structures of automotive applications, for instance.

c) Coiling and Annealing

In step c), the galvanized steel strip is first coiled and then annealed in a batch furnace. Herein, the term "batch furnace" refers a heat-treatment furnace that treats a stationary workpiece. This is distinguished from a conventional galvannealing process in which the
moving galvanized steel strip is first annealed in a continuously operating furnace and then coiled and optionally also cut into sheets to be delivered from the steel factory to the site having the hot press forming equipment.

In an alternative embodiment, the galvanized steel strip is first annealed in a continuous furnace, then coiled and thereafter further annealed in the batch furnace. This is also distinguished from the conventional galvannealing process in which steel strip is not annealed in a coil form. In other words, the galvanized steel strip within the meaning of this patent disclosure may be pre-annealed before coiling the strip and further annealing in the batch furnace.

It is preferred that the coiled steel strip is cooled to a temperature below 400°C, more preferably to a temperature below 250°C such as to the ambient temperature, before annealing the coil. This enables that diffusion process is dictated by solid state diffusion.

The galvanized steel strip may be coiled very tightly so as to reduce oxidation on the coating surface during annealing.

However, in a preferred embodiment, the galvanized steel strip may also be coiled and annealed by utilizing an open coil arrangement, as explained earlier. This solves the possible disadvantage relating to sticking of galvanized steel strip surfaces on each other during annealing the coil.

Preferably, the batch furnace is a bell-type furnace. Fig. 1 shows a typical sequence of steps performed when the coiled steel strip is annealed in such a bell-type furnace. In a first step, at least one steel coil is placed in a vertical position over an opening through which heat is introduced. As can be seen from Fig. 1 typically two or more of steel coils are laid on each other so that planar surfaces of these coils are arranged in parallel direction to each other. In a second step, an inner cover is placed over the steel coil. In a third step, a heating bell is placed over the inner cover and the steel coils are annealed by heating the atmosphere inside the heating bell. In a fourth step, the heating bell is replaced by a
cooling bell and the heated steel coils are cooled so that annealing is completed. In the final fifth step, the annealed steel coils are removed.

The annealing time is preferably more than 1 hour. Also the upper limit for the annealing time is preferably less than 200 hours. Naturally the annealing time is depending on annealing temperature, coating thickness, aluminum content in the galvanized coating. In addition coil size is affecting the complete annealing time that consists of heating, isothermic holding at annealing temperature and cooling. However, the term "annealing time" within the meaning of this patent disclosure refers to the isothermal part of said complete annealing time. The more preferred range for annealing time is 4 to 48 hours.

An annealing temperature of more than 250°C and less than 782°C is needed to achieve sufficient diffusion speed and avoid any melting of the coating. However, also in view of carbide spheroidization, the annealing temperature is preferably less than $A_{\text{i}}$ because higher temperature would cause austenite to form into the microstructure replacing the carbon rich areas. Generally $A_{\text{i}}$ is the temperature at which austenite begins to form during heating. A preferred range of the annealing temperature is 300°C - $A_{\text{i}}$, and a more preferred range is 300 - 450°C due to the long annealing times that the batch furnace annealing enables.

In a batch furnace, the heating temperature increases and decreases very slowly because of the substantial mass of the steel coil. This avoids molten phases in the coating as the diffusion of iron has time to proceed. However, the annealing temperature is preferably raised in stages to avoid melting of the different zinc-iron compounds.

The annealing time and temperature are set such that the average iron content of the annealed coating is more than 15 wt-%, preferably more than 20 wt-%. The coating comprising iron-zinc solid solution phase is less problematic during subsequent hot press forming than a coating comprising only iron-zinc intermetallic phases. The annealing time and temperature are most preferably set such that the average iron content of the annealed coating is more than 54 wt-%. The higher the average
iron content of the coating is the less iron-zinc intermetallic phase needs
to be transformed to the iron-zinc solid solution phase when the coating
is heated for hot press forming. An average iron content of more than 54
wt-% is most preferred because no iron-zinc solid solution phase needs
to be transformed to the iron-zinc solid solution phase before hot press
forming.

The annealing time and the temperature are preferably set such
that, as shown in Figs. 2,3 and 4, spheroidized iron carbides 5, 6 build up
at the grain boundaries of the microstructure 3 of the steel 1 and possibly
additionally also inside the grains 4 of the microstructure 3 of the steel 1.
This means that the microstructure 3 of the steel 1 has an iron carbide
structure consisting of spheroidized iron carbides 5, 6. Grains 4 of the
microstructure 3 referred herein naturally are grains of steel phases that
are typically occurring after galvanizing, such as grains of ferritic and/or
bainitic phases including also optionally small amount of martensitic
phases, depending on heat-treatment conditions during continuous
annealing prior to galvanizing. The steel having spheroidized iron
carbides formed in the microstructure 3 may be austenitized in a shorter
period of time or also possibly reduce the austenite grain size. If iron
carbides 5 are formed also inside the grains 4 in addition to iron carbides
6 formed at the grain boundaries, that may enable still more faster
austenitization of the steel material. This would further accelerate the
manufacture of a hot-pressed steel component, which is advantageous as
described earlier. Further possibly finer prior austenite grain structure
may result in improvements of mechanical properties of the hot press
formed component. Still further a galvannealed steel strip product
wherein the microstructure 3 of the steel 1 has an iron carbide structure
consisting of spheroidized iron carbides 5, 6, is excellent in terms of
formability, especially cold-formability.

Zinc oxide is not necessarily needed as a barrier layer during the
heating process for hot press forming if the coating comprises high
enough iron content such as in the iron-zinc solid solution phase. As a
result, an excessive amount of zinc oxide does not need to be removed to
enable successful painting or welding of the hot-pressed steel component after hot press forming. In order to reduce the amount of zinc oxide formed on the surface of the coating, the coiled steel strip is preferably annealed in an inert or reducing atmosphere. For this purpose, a protective gas such as nitrogen, hydrogen or a nitrogen/hydrogen blend may be supplied into the batch furnace. The aforementioned bell-type furnace is a batch furnace which enables the use of protective gas together with long annealing times. The atmosphere inside the heating bell and the annealing time and temperature are preferably set such that the amount of zinc oxide on the surface of the annealed steel strip is less than 10 mg/m$^2$, preferably less than 5 mg/m$^2$ on each side of the steel strip, as converted to the weight of zinc.

In case that a bell-type furnace is used for annealing, annealing may be completed by replacing the heating bell by the cooling bell that accelerates cooling of the steel coil compared with natural air cooling (see Fig. 1).

After cooling to room temperature, the galvannealed steel coil is delivered in the given coil form to a site having hot press forming equipment, or the galvannealed steel coil is cut to length and delivered in sheet form to the site having hot press forming equipment.

B) Galvannealed Steel Strip Product

As discussed above, the galvannealed steel strip product obtained by the aforementioned method A) of manufacturing a galvannealed steel strip product includes the steel coil as galvannealed and also a steel sheet cut from the galvannealed steel coil. In other words, the galvannealed steel strip product comprises a strip of steel made of hardenable steel alloy and plated with a galvannealed coating having an average iron content of more than 15 wt-%, preferably more than 20 wt-%. The galvannealed coating preferably comprises an iron-zinc solid solution phase. As mentioned above, the iron-zinc solid solution phase has a crystal structure in which zinc is incorporated into a lattice of iron. As the coating is obtained mainly by diffusion of iron from the steel into
the coating of galvanized steel strip, the amount of iron-zinc solid solution phase is higher at the interface between the steel and the coating than at the surface of the coating. The galvannealed coating forms an overlay on the steel strip and optionally has zinc oxide on the surface.

The higher the average iron content of the coating is, the less iron-zinc intermetallic phase needs to be transformed to the iron-zinc solid solution phase when the coating is heated for hot press forming. An average iron content of more than 54 wt-% is most preferred because no iron-zinc intermetallic phase needs to be transformed to the iron-zinc solid solution phase during the heating process for hot press forming.

The coating preferably has a coating weight of more than 160 g/m², preferably more than 180 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc. A high coating weight improves the galvanic corrosion resistance performance.

The amount of zinc oxide on the surface of the galvannealed steel strip product is less than 10 mg/m², preferably less than 5 mg/m² per side of the steel strip, as converted to the weight of zinc. This reduces the need for oxide removal after hot-pressing especially if the heating process for hot press forming has been quick.

In addition, the microstructure of the steel of steel strip has an iron carbide structure consisting of spheroidized iron carbides. As shown in Figs. 2, 3 and 4, the microstructure of the steel 1 of the steel strip comprises spheroidized iron carbides which are built up at the grain boundaries of the microstructure of the steel 1. It is more preferable that spheroidized iron carbides 5 are also additionally formed inside the grains 4 of the microstructure of the steel 1. Grains 4 of the microstructure 3 referred herein naturally are grains of steel phases that are typically occurring after galvanizing, such as grains of ferritic and/or bainitic phases including also possible small amount of martensitic phases, depending on heat-treatment conditions during continuous annealing prior to galvanizing. If iron carbides 5 are formed also inside the grains 4 in addition to iron carbides 6 formed at the grain boundaries,
that may enable still more faster austenitization of steel material. This would further accelerate the manufacture of a hot-pressed steel component, which is advantageous as described earlier. Further a possibly finer prior austenite grain structure may follow resulting in improvements of mechanical properties of the hot press formed component.

The carbide structure can be defined by visually inspection by optical microscopy. Samples are prepared by mounting the samples cut from steel strip, performing rough and fine polishing and finally etching with Nital. Said spheroidized iron carbides are distinguishable from iron carbides of pearlite having lamellar shape.

Said galvannealed steel strip product is preferably in a coil form.

C) Method of Manufacturing Hot-Pressed Steel Component

The method of manufacturing the hot-pressed steel component comprises the following steps in addition to the aforementioned steps a) to c):

d) blanking the galvannealed steel strip product to obtain a blank;

e) optionally cold press forming the blank to obtain a pre-shaped component;

f) heating the blank or pre-shaped component; and

g) hot press forming the heated blank or pre-shaped component.

Steps e) to h) are now explained in more detail.

d) Blanking

Irrespective of the delivery form of the galvannealed steel strip product, the galvannealed steel strip product is blanked in step d) to form sheet material that is needed to manufacture the hot-pressed steel component. Blanking is not restricted to any particular method. Die cutting or another commonly known mechanical method is however preferred.

e) Cold Press Forming
Step e) is an optional step for performing indirect hot press forming. If step e) is omitted, direct hot press forming for heated (austenitized) blank will be performed. Such direct press forming is preferred because the formed galvannealed coating can be more beneficial in this option.

In step e) the blank obtained in step d) is cold press formed to most of the final part shape at room temperature with a traditional press and die to obtain a pre-shaped component.

f) Heating

Heating process for hot press forming consists mainly of heating to a heating temperature and subsequent holding at the heating temperature.

In step f), the blank obtained in blanking step d) or the pre-shaped component obtained in step e) is heated in a heating oven to an austenitizing temperature at which austenite (γ-Fe) forms. This means that the blanks are heated to a temperature higher than \( A_{s1} \). \( A_{s1} \) is the lower limit because otherwise any press-hardenning cannot be achieved.

The heating temperature is preferably higher than \( A_{c3} \) at which transformation of ferrite to austenite is completed during heating. \( A_{c3} \) is the preferred lower limit because this way maximum amount of martensite can be formed in the microstructure during quench hardening and also the effect of grain refining can be more effective. However, the heating temperature at the end of heating is preferably not more than \( A_{c3} + 50°C \), preferably not more than \( A_{c3} + 30°C \). With certain steel compositions, the preferred heating temperature is in the range 880 to 950°C. This is because at higher temperatures excessive grain growth may occur. If the blank or pre-shaped component is heated to a temperature higher than \( A_{c3} \) but lower than \( A_{c3} + 50°C \), a microstructure consisting completely of fine grained austenite can be obtained.

Alternatively the heating temperature is in the dual-phase temperature range (\( A_{s1} \) to \( A_{c3} \)) in which a partial austenitization can be achieved. Advantageous partial austenitization can be facilitated due to
the local carbon enriched areas (i.e. austenitization of spheroidized iron carbides). By using this dual phase temperature range at austenitization, one can obtain microstructures of the hot-pressed steel component comprising local carbon enriched martensitic phase or local residual austenite areas inside the main phase consisting mainly of ferritic and/or bainitic phases. Due to the present invention, said carbon enriched martensite areas or residual austenite can be very close to each other.

During the heating process for hot press forming, further diffusion between iron and zinc occurs and the remaining iron-zinc intermetallic phases, if any, can be transformed to the iron-zinc solid solution phase. This transformation process takes the less time the higher the average iron content is.

It is preferred that heating to a heating temperature is kept short, such as less than 2 minutes or even less than 1 minute. Short holding may be necessary to let some time for austenite to homogenize, but it should be kept as minimal as possible to avoid grain growth and/or oxidation of coating. The present invention may help in this regard, as described earlier. This way most advantage is derived from the present invention which allows shortening the time needed during heating and holding to transform the brittle iron-zinc intermetallic phases in the coating to iron-zinc solid solution phase.

g) Hot Press Forming

In step g), the heated blank or pre-shaped component is hot-pressed at an elevated temperature in a press forming die so as to produce a shaped steel component.

The hot press forming step g) can be started within 3 minutes or even within 2 minutes calculated from starting of the heating step. This way finer grained austenite is obtained and also cycle times of the heating oven used in step f) and the press forming die used in step g) are better synchronized with a reasonable sized heating oven.

Hot press forming is carried out at a temperature in the range 450 - 850°C. Pre-cooling with suitable compositional design delaying
austenite decomposition may be used to bring the heated blank or pre-shaped component to the desired hot-pressing temperature.

After hot-pressing, the hot-pressed component is cooled. It is preferred that the hot-pressing step and the cooling step are carried out in the same press of the hot pressing forming equipment by rapidly cooling with closed forming dies. This way dimensional accuracy of the steel component is ensured because the mold prevents dimensional distortion which occurs during accelerated cooling such as quench hardening.

Cooling is preferably performed at a cooling rate sufficient to induce at least partial, preferably complete hardening of the shaped steel component. The cooling rate depends on the steel composition, the thickness of steel material and the degree of hot press forming, but can be higher than 10°C, or even higher than 30°C/s. For instance with 22MnB5 steel, a cooling rate higher than 30°C/s can be required to transform austenite completely to martensite. This way an ultra-high-strength steel (UHSS) component can be obtained. In other words, preferably the cooling is a quenching providing martensitic microstructure to the steel component.

After the cooling step, edge trimming and/or some perforations can be made to the steel component.

Conventionally removal of oxides on surface of the steel component is needed prior to painting or welding. However, if the amount of oxides formed on the surface of the galvannealed steel strip product is kept low as described in connection with the manufacture of the galvannealed steel strip product and if heating time is kept short as described in connection with the manufacture of the hot-pressed steel component, the removal of oxides can be reduced or even omitted.

In an example, a batch furnace annealing experiment was carried out for galvanized hot press forming steels made of hardenable steel alloy by using an annealing time of 48 hours and a temperature of 450°C. The microstructure of the steel shows an iron carbide structure
consisting of spheroidized iron carbides. In addition, the average iron content of the annealed coating was more than 20 wt-% and the galvannealed coating comprises an iron-zinc solid solution phase. An image of such carbide structure is shown in Fig 4. Similar results were achieved at an annealing temperature of 600°C.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the preferred embodiments described above but may vary within the scope of the claims.
Claims

1. A method of manufacturing a galvannealed steel strip product for hot press forming, comprising the following steps:
   - galvanizing a strip of steel made of hardenable steel alloy with zinc or zinc alloy;
   - coiling the galvanized steel strip; and
   - annealing the coiled steel strip in a batch furnace,
   - wherein the steel strip is coiled and annealed as galvanized, and
   - wherein the annealing time and temperature are set such that the average iron content of the annealed coating is more than 15 wt-%, preferably more than 20 wt-%.

2. The method of manufacturing a galvannealed steel strip product according to claim 1, wherein the coiled steel strip is annealed in an inert or reducing atmosphere.

3. The method of manufacturing a galvannealed steel strip product according to claim 1 or 2, wherein the annealing time and temperature are set such that an iron-zinc solid solution phase forms in the galvanized coating, said iron-zinc solid solution phase having a crystal structure in which zinc is incorporated into a lattice of iron.

4. The method of manufacturing a galvannealed steel strip product according to claim 3, wherein the annealing time and temperature are set such that the average iron content of the annealed coating is more than 54 wt-%.

5. The method of manufacturing a galvannealed steel strip product according to any one of claims 1 to 4, wherein the galvanized coating has a coating weight of more than 160 g/m², preferably more than 180 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc.
6. The method of manufacturing a galvannealed steel strip product according to any one of claims 1 to 5, wherein the hardenable steel alloy has the following composition:

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>0.08 - 0.45 wt-%</td>
</tr>
<tr>
<td>Mn + Cr</td>
<td>0.5 - 3.5 wt-%</td>
</tr>
<tr>
<td>Si</td>
<td>&lt; 1 wt-%</td>
</tr>
<tr>
<td>Al</td>
<td>&lt; 0.2 wt-%</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt; 1.0 wt-%</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt; 1.0 wt-%</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 0.01 wt-%</td>
</tr>
<tr>
<td>Ti</td>
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<tr>
<td>Nb</td>
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<td>Mo</td>
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<tr>
<td>V</td>
<td>&lt; 0.5 wt-%</td>
</tr>
<tr>
<td>Ca</td>
<td>&lt; 0.01 wt-%,</td>
</tr>
</tbody>
</table>

the balance being iron and residual contents or unavoidable impurities.

7. The method of manufacturing a galvannealed steel strip product according to any one of claims 1 to 6, wherein the annealing time and temperature are set such that a microstructure (3) of the steel (1) having an iron carbide structure consisting of spheroidized iron carbides (5, 6) is obtained.

8. The method of manufacturing a galvannealed steel strip (1) product according to any one of claims 1 to 7, wherein the annealing temperature is raised in stages to avoid molten phases in the coating.

9. A method of manufacturing a hot-pressed steel component from a galvannealed steel strip product, comprising the following steps:
   - manufacturing a galvannealed steel strip product according to the method defined in any one of claims 1 to 8;
blanking the galvannealed steel strip product to obtain a blank; optionally cold press forming the blank to obtain a pre-shaped component; heating the blank or pre-shaped component; and hot press forming the heated blank or pre-shaped component.

10. The method of manufacturing a hot-pressed steel component according to claim 9, wherein the hot press forming step is started within 3 minutes, preferably within 2 minutes calculated from starting of the heating step.

11. A galvannealed steel strip product for hot press forming, comprising a strip of steel (1) made of hardenable steel alloy and plated with a galvannealed coating (2) optionally having zinc oxide on the surface, characterized in that the galvannealed coating (2) comprises an iron-zinc solid solution phase, said iron-zinc solid solution phase having a crystal structure in which zinc is incorporated into a lattice of iron, and the microstructure (3) of the steel (1) has an iron carbide structure consisting of spheroidized iron carbides (5, 6).

12. The galvannealed steel strip product according to claim 11, wherein the amount of zinc oxide on the surface of the galvannealed coating (2), if present, is less than 10 mg/m², preferably less than 5 mg/m² per side of the steel strip, as converted to the weight of zinc.

13. The galvannealed steel strip product according to claim 11 or 12, wherein the average iron content of the galvannealed coating (2) is more than 15 wt-%, preferably more than 20 wt-%.

14. The galvannealed steel strip product according to claim 13, wherein the average iron content of the galvannealed coating (2) is more than 54 wt-%.
15. The galvannealed steel strip product according to any one of claims 11 to 14, wherein the galvannealed coating (2) has a coating weight of more than 160 g/m², preferably more than 180 g/m² as measured from both sides of the steel strip and as converted to the weight of zinc.

16. The galvannealed steel strip product according to any one of claims 11 to 15, wherein the hardenable steel alloy has the following composition:

<table>
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<tr>
<th>Element</th>
<th>Composition</th>
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<td>C</td>
<td>0.08 - 0.45 wt-%</td>
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<td>Mn + Cr</td>
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the balance being iron and residual contents or unavoidable impurities.

17. The galvannealed steel strip product according to any one of claims 11 to 16, wherein the galvannealed steel strip is in a coil form.
## A. CLASSIFICATION OF SUBJECT MATTER

|------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|

According to International Patent Classification (IPC) or to both national classification and IPC.

## B. FIELDS SEARCHED

| Minimum documentation searched (classification system followed by classification symbols) |
| C21D C23C C22C F27B |

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[Box X] Further documents are listed in the continuation of Box C. [Box X] See patent family annex.

* Special categories of cited documents:
  - "A" document defining the general state of the art which is not considered to be of particular relevance
  - "E" earlier application or patent but published on or after the international filing date
  - "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - "O" document referring to an oral disclosure, use, exhibition or other means
  - "P" document published prior to the international filing date but later than the priority date claimed

* "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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* "A" document member of the same patent family

Date of the actual completion of the international search: 3 November 2014

Date of mailing of the international search report: 13/11/2014

Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer: Catana, Cosmin
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