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METAL-COATED STEEL STRIP

ABSTRACT

5 An Al-Zn-Si-Mg alloy coated strip that has Mg₂Si particles in the coating
microstructure is disclosed. The distribution of Mg₂Si particles is such that the surface
of the coating has only a small proportion of Mg₂Si particles or is at least substantially
free of any Mg₂Si particles.

METAL-COATED STEEL STRIP

The present application is a divisional of Australian Patent Application No 2024201691, which has divisional parents in Australian Patent Application Nos 2021221876, 2019222812, 2016256784, 2014253542 and 2009225257, the latter of which is a national phase entry of International Patent Application No PCT/AU2009/000305, which claims the benefit of and priority to Australian Patent Application Nos 2008901223 and 2008901224, the entire contents of each of which are incorporated herein by reference.

The present invention relates to strip, typically steel strip, which has a corrosion-resistant metal alloy coating.

The present invention relates particularly to a corrosion-resistant metal alloy coating that contains aluminium-zinc-silicon-magnesium as the main elements in the alloy, and is hereinafter referred to as an "Al-Zn-Si-Mg alloy" on this basis. The alloy coating may contain other elements that are present as deliberate alloying additions or as unavoidable impurities. Hence, the phrase "Al-Zn-Si-Mg alloy" is understood to cover alloys that contain such other elements and the other elements may be deliberate alloying additions or as unavoidable impurities.

The present invention relates particularly but not exclusively to steel strip that is coated with the above-described Al-Zn-Si-Mg alloy and can be cold formed (e.g. by roll forming) into an end-use product, such as roofing products.

Typically, the Al-Zn-Si-Mg alloy comprises the following ranges in % by weight of the elements aluminium, zinc, silicon, and magnesium:

| | |
|------------|-------------|
| Aluminium: | 40 to 60 % |
| Zinc: | 40 to 60 % |
| Silicon: | 0.3 to 3% |
| Magnesium | 0.3 to 10 % |

Typically, the corrosion-resistant metal alloy coating is formed on steel strip by a hot dip coating method.

In the conventional hot-dip metal coating method, steel strip generally passes through one or more heat treatment furnaces and thereafter into and through a

bath of molten metal alloy held in a coating pot. The heat treatment furnace that is adjacent a coating pot has an outlet snout that extends downwardly to a location below the upper surface of the bath.

5 The metal alloy is usually maintained molten in the coating pot by the use of heating inductors. The strip usually exits the heat treatment furnaces via an outlet end section in the form of an elongated furnace exit chute or snout that dips into the bath. Within the bath the strip passes around one or more sink rolls and is taken upwardly out of the bath and is coated with the metal alloy as it passes through the bath.

10 After leaving the coating bath the metal alloy coated strip passes through a coating thickness control station, such as a gas knife or gas wiping station, at which its coated surfaces are subjected to jets of wiping gas to control the thickness of the coating.

15 The metal alloy coated strip then passes through a cooling section and is subjected to forced cooling.

The cooled metal alloy coated strip may thereafter be optionally conditioned by passing the coated strip successively through a skin pass rolling section (also known as a temper rolling section) and a tension levelling section. The conditioned strip is coiled at a coiling station.

20 A 55%Al-Zn alloy coating is a well known metal alloy coating for steel strip. After solidification, a 55%Al-Zn alloy coating normally consists of α -Al dendrites and a β -Zn phase in the inter-dendritic regions of the coating.

25 It is known to add silicon to the coating alloy composition to prevent excessive alloying between the steel substrate and the molten coating in the hot-dip coating method. A portion of the silicon takes part in a quaternary alloy layer formation but the majority of the silicon precipitates as needle-like, pure silicon particles during solidification. These needle-like silicon particles are also present in the inter-dendritic regions of the coating.

30 Any reference to or discussion of any document, act or item of knowledge in this specification is included solely for the purpose of providing a context for the present invention. It is not suggested or represented that any of these matters or

any combination thereof formed at the priority date part of the common general knowledge, or was known to be relevant to an attempt to solve any problem with which this specification is concerned.

5 For the avoidance of doubt, in this specification, the terms 'comprises', 'comprising', 'includes', 'including', or similar terms are intended to mean a non-exclusive inclusion, such that a method, system or apparatus that comprises a list of elements does not include those elements solely, but may well include other elements not listed.

10 It has been found by the applicant that when Mg is included in a 55%Al-Zn-Si alloy coating composition, Mg brings about certain beneficial effects on product performance, such as improved cut-edge protection, by changing the nature of corrosion products formed.

15 However, it has also been found by the applicant that Mg reacts with Si to form a Mg_2Si phase and that the formation of the Mg_2Si phase compromises the above-mentioned beneficial effects of Mg in a number of ways.

One particular way, which is the focus of the present invention is a surface defect called "mottling". The applicant has found that mottling can occur in Al-Zn-Si-Mg alloy coatings under certain solidification conditions. Mottling is related to the presence of the Mg_2Si phase on the coating surface.

20 More particularly, mottling is a defect where a large number of coarse Mg_2Si particles cluster together on the surface of the coating, resulting in a blotchy surface appearance that is not acceptable from an aesthetic viewpoint. More particularly, the clustered Mg_2Si particles form darker regions approximately 1-5 mm in size and introduce non-uniformity in the appearance of the coating which makes the
25 coated product unsuitable for applications where a uniform appearance is important.

The above description is not to be taken as an admission of the common general knowledge in Australia or elsewhere.

30 According to a first aspect of the present invention there is provided a hot-dip coating method to form a corrosion-resistant coated steel strip, the method comprising: passing a steel strip through a hot dip coating bath comprising aluminium, zinc, silicon, and magnesium to form an alloy coating on the steel strip comprising, in

weight %, 40% to 60% aluminium; 40% to 60% zinc; 0.3% to 3% silicon; and 0.3% to 10% magnesium; controlling a short range coating thickness variation of the alloy coating on the steel strip to be no more than 40% in a 5 mm diameter section of the alloy coating; and cooling the alloy coating on the steel strip; wherein the alloy coating
5 has a microstructure comprising Mg_2Si particles, and wherein controlling the short range coating thickness variation controls the distribution of Mg_2Si within the microstructure such that the surface of the alloy coating has no more than 10 wt% of Mg_2Si particles to thereby enhance corrosion resistance of the alloy coating.

10 According to another aspect of the present invention there is provided a coated steel strip produced according to the first aspect.

Another aspect of the invention disclosed herein relates to an Al-Zn-Si-Mg alloy coated strip that has Mg_2Si particles in the coating microstructure with the distribution of Mg_2Si particles being such that the surface of the coating has only a small proportion of Mg_2Si particles or is at least substantially free of any Mg_2Si
15 particles.

The applicant has found that the above-described distribution of Mg_2Si particles in the coating microstructure provides significant advantages and can be achieved by any one or more of:

- (a) strontium additions in the coating alloy,
- 20 (b) selection of the cooling rate during solidification of coated strip for a given coating mass (i.e. coating thickness) exiting a coating bath; and
- (c) minimising variations in coating thickness.

The applicant has found that Sr additions described in more detail below control the distribution characteristics of the Mg_2Si phase in the thickness direction of
25 an Al-Zn-Si-Mg alloy coating so that the surface of the coating has only a small proportion of Mg_2Si particles or is at least substantially free of Mg_2Si particles, whereby there is a considerably lower risk of Mg_2Si mottling.

In particular, the applicant has found that when at least 250 ppm Sr, preferably 250-3000 ppm Sr, is added to a coating bath containing an Al-Zn-Si-Mg alloy
30 the distribution characteristics of the Mg_2Si phase in the coating thickness direction are

completely changed by this addition of Sr from the distribution that is present when there is no Sr in the coating bath. Specifically, the applicant has found that these additions of Sr promote the formation of a surface of the coating that has only a small proportion of Mg₂Si particles or is free of any Mg₂Si particles and consequently a considerably lower risk of mottling on the surface.

The applicant has also found that selecting the cooling rate during solidification of a coated strip exiting a coating bath to be below a threshold cooling rate, typically below 80°C/sec for coating masses less than 100 grams per square metre of strip surface per side, controls the distribution characteristics of the Mg₂Si phase so that the surface has only a small proportion of Mg₂Si particles or is at least substantially free of Mg₂Si particles, whereby there is a considerably lower risk of Mg₂Si mottling.

The applicant has also found that minimising coating thickness variations controls the distribution characteristics of the Mg₂Si phase so that the surface has only a small proportion of Mg₂Si particles or is at least substantially free of Mg₂Si particles, whereby there is a considerably lower risk of Mg₂Si mottling. As is the case with Sr addition and selection of cooling rate during solidification, the resultant coating microstructure is advantageous in terms of appearance, enhanced corrosion resistance and improved coating ductility.

Another aspect of the invention disclosed herein relates to an Al-Zn-Si-Mg alloy coated steel strip that comprises a coating of an Al-Zn-Si-Mg alloy on a steel strip, with the microstructure of the coating comprising Mg₂Si particles, and with the distribution of the Mg₂Si particles being such that there is only a small proportion of Mg₂Si particles or at least substantially no Mg₂Si particles in the surface of the coating.

The small proportion of Mg₂Si particles in the surface region of the coating may be no more than 10 wt.% of the Mg₂Si particles.

Typically, the Al-Zn-Si-Mg alloy comprises the following ranges in % by weight of the elements aluminium, zinc, silicon, and magnesium:

| | |
|------------|------------|
| Aluminium: | 40 to 60 % |
| Zinc: | 40 to 60 % |

| | |
|-----------|-------------|
| Silicon: | 0.3 to 3% |
| Magnesium | 0.3 to 10 % |

The Al-Zn-Si-Mg alloy may also contain other elements, such as, by way of example any one or more of iron, vanadium, chromium, and strontium.

5 Typically, the coating thickness is less than 30 μ m.

Preferably the coating thickness is greater than 7 μ m.

Preferably the coating contains more than 250 ppm Sr, with the Sr addition promoting the formation of the above distribution of Mg₂Si particles in the coating.

10 Preferably the coating contains more than 500 ppm Sr.

Preferably the coating contains more than 1000 ppm Sr.

Preferably the coating contains less than 3000 ppm Sr.

The Al-Zn-Si-Mg-Sr alloy coating may contain other elements as deliberate additions or as unavoidable impurities.

15 Preferably there are minimal coating thickness variations.

Another aspect of the invention disclosed herein relates to a hot-dip coating method for forming a coating of a corrosion-resistant Al-Zn-Si-Mg alloy on a steel strip that is characterised by passing the steel strip through a hot dip coating bath that contains Al, Zn, Si, Mg, and more than 250 ppm Sr and optionally other elements and forming an alloy coating on the strip that has Mg₂Si particles in the coating microstructure with the distribution of the Mg₂Si particles being such that there is only a small proportion of Mg₂Si particles or substantially no Mg₂Si particles in the surface of the coating.

25 The small proportion of Mg₂Si particles in the surface region of the coating may be no more than 10 wt.% of the Mg₂Si particles.

Preferably the coating contains more than 500 ppm Sr.

Preferably the coating contains at least 1000 ppm Sr.

Preferably the molten bath contains less than 3000ppm Sr.

The Al-Zn-Si-Mg-Sr alloy coating may contain other elements as deliberate additions or as unavoidable impurities.

Another aspect of the invention disclosed herein relates to a hot-dip
5 coating method for forming a coating of a corrosion-resistant Al-Zn-Si-Mg alloy on a
steel strip that is characterised by passing the steel strip through a hot dip coating bath
that contains Al, Zn, Si, and Mg and optionally other elements and forming an alloy
coating on the strip, and cooling coated strip exiting the coating bath during
solidification of the coating at a rate that is controlled so that the distribution of Mg₂Si
10 particles in the coating microstructure is such that there is only a small proportion of
Mg₂Si particles or substantially no Mg₂Si particles in the surface of the coating.

The small proportion of Mg₂Si particles in the surface region of the
coating may be no more than 10 wt.% of the Mg₂Si particles.

Preferably the method comprises selecting the cooling rate for coated
15 strip exiting the coating bath to be less than a threshold cooling rate.

In any given situation, the selection of the required cooling rate is related
to the coating thickness (or coating mass).

Preferably the method comprises selecting the cooling rate for coated
strip exiting the coating bath to be less than 80°C/sec for coating masses up to 75
20 grams per square metre of strip surface per side.

Preferably the method comprises selecting the cooling rate for coated
strip exiting the coating bath to be less than 50°C/sec for coating masses of 75-100
grams per square metre of strip surface per side.

Typically, the method comprises selecting the cooling rate to be at least
25 11°C/sec.

By way of example, for a coating having an average thickness of 22µm,
during solidification preferably the cooling rates are as follows:

(a) 55°C/sec in a temperature range of 600-530°C,

(b) 70°C/sec in a temperature range of 530-500°C, and

(c) 80°C/sec in a temperature range of 500-300°C.

The coating bath and the coating on steel strip coated in the bath may contain Sr.

5 Another aspect of the invention disclosed herein relates to a hot-dip coating method for forming a coating of a corrosion-resistant Al-Zn-Si-Mg alloy on a steel strip comprising passing the steel strip through a hot dip coating bath that contains Al, Zn, Si, and Mg and optionally other elements and forming an alloy coating on the strip with minimal variation in the thickness of the coating of no more than 40%
10 in a 5 mm diameter section so that the distribution of Mg₂Si particles in the coating microstructure is such that there is only a small proportion of Mg₂Si particles or substantially no Mg₂Si particles in the surface of the coating.

The small proportion of Mg₂Si particles in the surface region of the coating may be no more than 10 wt.% of the Mg₂Si particles.

15 Preferably the coating thickness variation should be no more than 40% in a 5 mm diameter section of the coating.

More preferably the coating thickness variation should be no more than 30% in a 5 mm diameter section of the coating.

20 In any given situation, the selection of an appropriate thickness variation is related to the coating thickness (or coating mass).

By way of example, for a coating thickness of 22μm, preferably the maximum thickness in any region of the coating greater than 1mm in diameter should be 27μm.

25 Preferably the method comprises selecting the cooling rate during solidification of coated strip exiting the coating bath to be less than a threshold cooling rate.

The coating bath and the coating on steel strip coated in the bath may contain Sr.

The hot-dip coating method may be the conventional method described above or any other suitable method.

The advantages of the invention include the following advantages.

- Elimination of mottling defect and improved first-time-prime production rate. The risk of the mottling defect is at least substantially eliminated and the surface of the resultant coating maintains a beautiful, silvery metallic appearance. As a result, first-time-prime production rate is improved and profitability is boosted.
- Prevention of mottling defect by the addition of Sr allows the use of higher cooling rates, reducing the length of cooling equipment required after the pot.

Example

The applicant has carried out laboratory experiments on a series of 55%Al-Zn-1.5%Si-2.0%Mg alloy compositions having up to 3000 ppm Sr coated on steel substrates.

The purpose of these experiments was to investigate the impact of Sr on mottling in the surface of the coatings.

Figure 1 summarises the results of one set of experiments carried out by the applicant that illustrate the present invention.

The left hand side of the Figure comprises a top plan view of a coated steel substrate and a cross-section through the coating with the coating comprising a 55%Al-Zn-1.5%Si-2.0%Mg alloy with no Sr. The coating was not formed having regard to the selection of cooling rate during solidification and coating thickness variations discussed above.

The mottling that results from such a coating composition is identified by the arrow in the top plan view. It is evident from the cross-section that Mg_2Si particles are distributed throughout the coating thickness. This is a problem for the reasons stated above.

The right hand side of the Figure comprises a top plan view of a coated steel substrate and a cross-section through the coating, with the coating comprising a 55%Al-Zn-1.5%Si-2.0%Mg alloy and 500 ppm Sr. A complete absence of mottling is evident from the top plan view. In addition, the cross-section illustrates upper and lower regions at the coating surface and at the interface with the steel substrate that are completely free of Mg₂Si particles, with the Mg₂Si particles being confined to a central band of the coating. This is advantageous for the reasons stated above.

The photomicrographs of the Figure illustrate clearly the benefits of the addition of Sr to an Al-Zn-Si-Mg coating alloy.

The laboratory experiments found that the microstructure shown in the right hand side of the Figure were formed with Sr additions in the range of 250-3000 ppm.

The applicant has also carried out line trials on 55%Al-Zn-1.5%Si-2.0%Mg alloy composition (not containing Sr) coated on steel substrates.

The purpose of these trials was to investigate the impact of cooling rates and coating masses on mottling in the surface of the coatings.

The trials covered a range of coating masses from 60 to 100 grams per square metre surface per side of strip, with cooling rates up to 90°C/sec.

The applicant found two factors that affected the coating microstructure, particularly the distribution of Mg₂Si particles in the coatings, in the trials.

The first factor is the effect of the cooling rate of the strip exiting the coating bath before completing the coating solidification. The applicant found that controlling the cooling rate makes it possible to avoid mottling.

By way of example, the applicant found that for a AZ150 class coating (or 75 grams of coating per square metre surface per side of strip - refer to Australia Standard AS1397-2001), if the cooling rate is greater than 80°C/sec, Mg₂Si particles formed on the surface of the coating. In particular, when the cooling rate was greater than 100°C/sec, mottling occurred.

The applicant also found that for the same coating it is not desirable that the cooling rate be too low, particularly below 11°C/sec, as in this case the coating

develops a defective “bamboo” structure, whereby the zinc-rich phases forms a vertically straight corrosion path from the coating surface to the steel interface, which compromises the corrosion performance of the coating.

5 Therefore, for a AZ150 class coating, under the experimental conditions tested, the cooling rate should be controlled to be in a range of 11-80°C/sec to avoid mottling on the surface.

On the other hand, the applicant also found that for a AZ200 class coating, if the cooling rate was greater than 50°C/sec, Mg₂Si particles formed on the surface of the coating and mottling occurred.

10 Therefore, for a AZ200 class coating, under the experimental conditions tested, a cooling rate in a range of 11-50°C/sec is desirable.

The second important factor found by the applicant is the uniformness of coating thickness across the strip surface.

15 The applicant found that the coating on the strip surface normally had thickness variations that are (a) long range (across the entire strip width, measured by the “weight-strip-weight” method on a 50mm diameter disc) and (b) short range (across every 25 mm length in the strip width direction, measured in the cross-section of the coating under a microscope with 500× magnification). In a production situation, the long range thickness variation is normally regulated to meet the minimum coating mass requirements as defined in relevant national standards. In a production situation, as far
20 is the applicant is aware, there is no regulation for short range thickness variation, as long as the minimum coating mass requirements as defined in relevant national standards are met.

25 However, the applicant found that short range coating thickness variations could be very high, and special operational measures had to be applied to keep the variations under control. It was not uncommon in the experimental work for the coating thickness to change by a factor of two or more over a distance as short as 5 mm, even when the product perfectly met the minimum coating mass requirements as defined in relevant national standards. This short range coating thickness variation
30 had a pronounced impact on the Mg₂Si particles in the surface of coatings.

By way of example, the applicant found that for a AZ150 class coating even in the desirable cooling rate ranges as described above, if the short range coating thickness variation was greater than 40% above the nominal coating thickness within a distance of 5 mm across the strip surface, Mg₂Si particles formed on the surface of the coating and thereby increased the risk of mottling.

Therefore, under the experimental conditions tested, the short range coating thickness variation should be controlled to no greater than 40% above the nominal coating thickness within a distance of 5mm across the strip surface to avoid mottling.

In the context of the conventional hot-dip metal coating method and coating line described generally above on pages 1-2, the gas wiping apparatus directs jets of wiping gas via an outlet towards a coated steel strip with a molten alloy coating on the strip immediately after the coated strip leaves the coating bath. The jets of wiping gas control the thickness of the coating on the strip.

A conventional coating line was used for the above-described line trials. In the case of the coating line used for the line trials, the wiping gas outlets were situated approximately 350 mm above the coating bath, approximately 14 mm from the coated steel strip and applied a pressure of approximately 7 kPa.

The special operational measures that may be used to keep the short range coating thickness variations under control include adjustments to the gas wiping apparatus at a coating thickness control station above the coating bath of the coating line, and/or the introduction of a stabiliser to stabilise the coated strip between the jets of wiping gas.

The adjustment options for the gas wiping apparatus are known to the skilled person and include, by way of example, (a) adjusting by reducing the height of the wiping gas outlets of the gas wiping apparatus above the coating bath so that it is closer to the coating bath and/or (b) adjusting by reducing the distance between the wiping gas outlets and the coated strip whilst reducing the pressure of the wiping gas.

A stabiliser (such as an electromagnetic strip stabiliser or an air flotation stabiliser) is known to the skilled person and stabilises the coated strip between the

wiping gas outlets such that the distance variation between the wiping gas outlets and the coated strip is reduced.

The research work carried out by the applicant on the solidification of Al-Zn-Si-Mg coatings, which is extensive and is described in part above, has helped the applicant to develop an understanding of the formation of the Mg_2Si phase in a coating and the factors affecting its distribution in the coating. Whilst the applicant does not wish to be bound by the following discussion, this understanding is as set out below.

When an Al-Zn-Si-Mg alloy coating is cooled to a temperature in the vicinity of $560^\circ C$, the α -Al phase is the first phase to nucleate. The α -Al phase then grows into a dendritic form. As the α -Al phase grows, Mg and Si, along with other solute elements, are rejected into the molten liquid phase and thus the remaining molten liquid in the interdendritic regions is enriched in Mg and Si.

When the enrichment of Mg and Si in the interdendritic regions reaches a certain level, the Mg_2Si phase starts to form, which also corresponds to a temperature around $465^\circ C$. For simplification, it will be assumed that an interdendritic region near the outer surface of the coating is region A and another interdendritic region near the quaternary intermetallic alloy layer at the steel strip surface is region B. It will also be assumed that the level of enrichment in Mg and Si is the same in region A as in region B.

At or below $465^\circ C$, the Mg_2Si phase has the same tendency to nucleate in region A as in region B. However, the principles of physical metallurgy teach us that a new phase will preferably nucleate at a site whereupon the resultant system free energy is the minimum. The Mg_2Si phase would normally nucleate preferably on the quaternary intermetallic alloy layer in region B provided the coating bath does not contain Sr (the role of Sr with Sr-containing coatings is discussed below). The applicant believes that this is in accordance with the principles stated above, in that there is a certain similarity in crystal lattice structure between the quaternary intermetallic alloy phase and the Mg_2Si phase, which favours the nucleation of Mg_2Si phase by minimizing any increase in system free energy. In comparison, for the Mg_2Si phase to nucleate on the surface oxide of the coating in region A, the increase in system free energy would have been greater.

Upon nucleation in region B, the Mg_2Si phase grows upwardly, along the molten liquid channels in the interdendritic regions, towards region A. At the growth front of the Mg_2Si phase (region C), the molten liquid phase becomes depleted in Mg and Si (depending on the partition coefficients of Mg and Si between the liquid phase and the Mg_2Si phase), compared with that in region A. Thus a diffusion couple forms between region A and region C. In other words, Mg and Si in the molten liquid phase will diffuse from region A to region C. Note that the growth of the α -Al phase in region A means that region A is always enriched in Mg and Si and the tendency for the Mg_2Si phase to nucleate in region A always exists because the liquid phase is "undercooled" with regard to the Mg_2Si phase.

Whether the Mg_2Si phase is to nucleate in region A, or Mg and Si are to keep diffusing from region A to region C, will depend on the level of Mg and Si enrichment in region A, relevant to the local temperature, which in turn depends on the balance between the amount of Mg and Si being rejected into that region by the α -Al growth and the amount of Mg and Si being moved away from that region by the diffusion. The time available for the diffusion is also limited, as the Mg_2Si nucleation/growth process has to be completed at a temperature around $380^\circ C$, before the $L \rightarrow Al-Zn$ eutectic reaction takes place, wherein L depicts the molten liquid phase.

The applicant has found that controlling the balance between the time available for diffusion and the diffusion distance for Mg and Si can control the subsequent nucleation or growth of the Mg_2Si phase or the final distribution of the Mg_2Si phase in the coating thickness direction.

In particular, the applicant has found that for a set coating thickness, the cooling rate should be regulated to a particular range, and more particularly not to exceed a threshold temperature, to avoid the risk for the Mg_2Si phase to nucleate in region A. This is because for a set coating thickness (or a relatively constant diffusion distance between regions A and C), a higher cooling rate will drive the α -Al phase to grow faster, resulting in more Mg and Si being rejected into the liquid phase in region A and a greater enrichment of Mg and Si, or a higher risk for the Mg_2Si phase to nucleate, in region A (which is undesirable).

On the other hand, for a set cooling rate, a thicker coating (or a thicker local coating region) will increase the diffusion distance between region A and region

C, resulting in a smaller amount of Mg and Si being able to move from region A to region C by the diffusion within a set time and in turn a greater enrichment of Mg and Si, or a higher risk for the Mg_2Si phase to nucleate, in region A (which is undesirable).

Practically, the applicant has found that, to achieve the distribution of Mg_2Si particles of the present invention, i.e. to avoid mottling defect on the surface of a coated strip, the cooling rate for coated strip exiting the coating bath has to be in a range of 11-80°C/sec for coating masses up to 75 grams per square metre of strip surface per side and in a range 11-50°C/sec for coating masses of 75-100 grams per square metre of strip surface per side. The short range coating thickness variation also has to be controlled to be no greater than 40% above the nominal coating thickness within a distance of 5 mm across the strip surface to achieve the distribution of Mg_2Si particles of the present invention.

The applicant has also found that, when Sr is present in a coating bath, the above described kinetics of Mg_2Si nucleation can be significantly influenced. At certain Sr concentration levels, Sr strongly segregates into the quaternary alloy layer (i.e. changes the chemistry of the quaternary alloy phase). Sr also changes the characteristics of surface oxidation of the molten coating, resulting in a thinner surface oxide on the coating surface. Such changes alter significantly the preferential nucleation sites for the Mg_2Si phase and, as a result, the distribution pattern of the Mg_2Si phase in the coating thickness direction. In particular, the applicant has found that, Sr at concentrations 250-3000ppm in the coating bath makes it virtually impossible for the Mg_2Si phase to nucleate on the quaternary alloy layer or on the surface oxide, presumably due to the very high level of increase in system free energy would otherwise be generated. Instead, the Mg_2Si phase can only nucleate at the central region of the coating in the thickness direction, resulting in a coating structure that is substantially free of Mg_2Si at both the coating outer surface region and the region near the steel surface. Therefore, Sr additions in the range 250-3000ppm are proposed as one of the effective means to achieve a desired distribution of Mg_2Si particles in a coating.

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

In this context, whilst the above description of the present invention focuses on (a) the addition of Sr to Al-Zn-Si-Mg coating alloys, (b) cooling rates (for a

given coating mass) and (c) control of short range coating thickness variation as means for achieving a desired distribution of Mg_2Si particles in coatings, i.e. at least substantially no Mg_2Si particles in the surface of a coating, the present invention is not so limited and extends to the use of any suitable means to achieve the desired

5 distribution of Mg_2Si particles in the coating.

The claims defining the invention are as follows:

1. A hot-dip coating method for forming a coating of a corrosion-resistant Al-Zn-Si-Mg alloy on a steel strip comprising passing the steel strip through a hot dip coating bath that contains Al, Zn, Si, and Mg and optionally other elements and forming
5 an alloy coating on the strip with a variation in thickness of the coating of no more than 40% in a 5 mm diameter section so that the distribution of Mg₂Si particles in the coating microstructure is such that there is only a small proportion of Mg₂Si particles or substantially no Mg₂Si particles in the surface of the coating.

2. The method defined in claim 1 comprising forming the alloy coating so
10 that there are no Mg₂Si particles in the surface of the coating.

3. The method defined in claim 1 or 2 wherein the small proportion of Mg₂Si particles in the surface of the coating is no more than 10wt.% of the Mg₂Si particles.

4. The method defined in any one of claims 1 to 3 wherein the coating thickness variation is no more than 30% in a 5 mm diameter section of the coating.

15 5. The method defined in any one of claims 1 to 4 wherein, for a coating thickness of 22µm, the maximum thickness in any region of the coating greater than 1mm in diameter is 27µm.

6. The method defined in any one of claims 1 to 5 comprising selecting the cooling rate during solidification of coated strip exiting the coating bath to be less than
20 a threshold cooling rate.

7. The method defined in any one of claims 1 to 6 comprising selecting the cooling rate for coated strip exiting the coating bath to be less than 80°C/sec for coating masses up to 75 grams per square metre of strip surface per side.

8. The method defined any one of claims 1 to 6 comprising selecting the
25 cooling rate for coated strip exiting the coating bath to be less than 50°C/sec for coating masses of 75-100 grams per square metre of strip surface per side.

9. The method defined in any one of claims 1 to 8 wherein the coating comprises the following ranges in % by weight of the elements aluminium, zinc, silicon, and magnesium:

- Aluminium: 40 to 60 %
- Zinc: 40 to 60 %
- Silicon: 0.3 to 3%
- Magnesium: 0.3 to 10 %.

10. The method defined in any one of claims 1 to 9 wherein the coating contains more than 250 ppm Sr.

11. The method defined in any one of claims 1 to 10 wherein the coating contains less than 3000 ppm Sr.

12. The method defined in any one of claims 1 to 11 comprising forming the coating to have a thickness of less than 30µm.

13. The method defined in any one of claims 1 to 12 comprising forming the coating to have a thickness of greater than 7µm.

14. A steel strip having a coating of a corrosion resistant Al-Zn-Si-Mg alloy formed by the method defined in any one of claims 1 to 13.

15. An Al-Zn-Si-Mg alloy coated strip that has Mg₂Si particles in the coating with the distribution of Mg₂Si particles being such that a surface of the coating has only a small proportion of Mg₂Si particles or is at least substantially free of any Mg₂Si particles formed by the method defined in any one of claims 1 to 14.

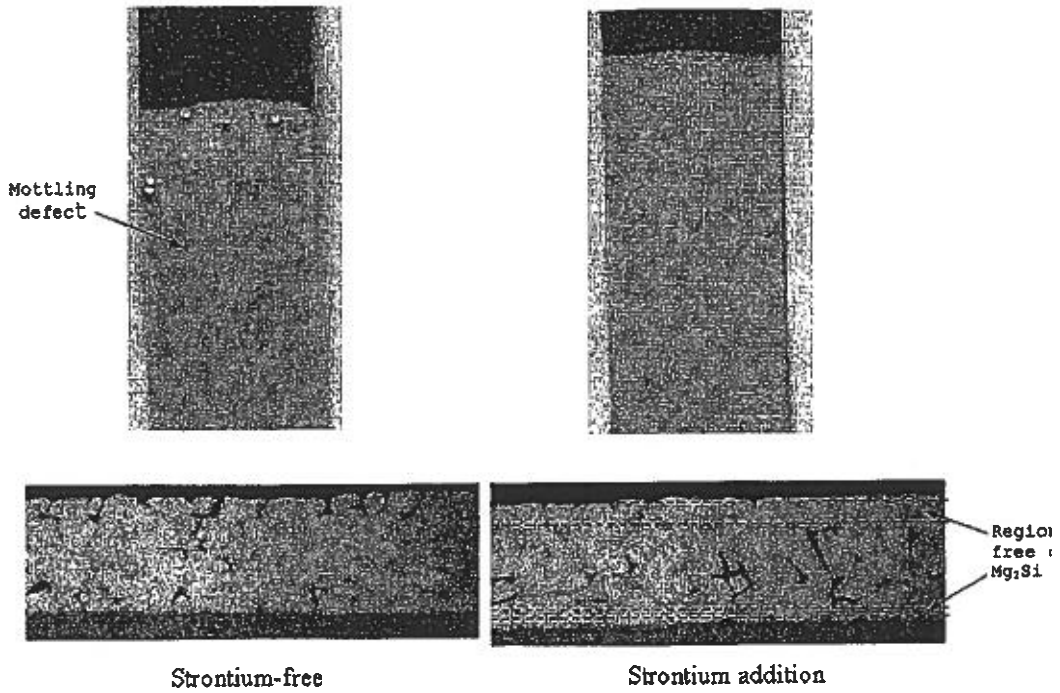


Figure 1 Sr additions in a 55%Al-Zn-1.5%Si-2.0%Mg coating eliminate the surface mottling defect and change the distribution pattern of the Mg₂Si phase in the coating thickness direction.

FIGURE 1