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A Comparative Study of various Oxidation Preventive Coating for Hot Steel substrate (undergoing Forging Operation)

Siddhant Soni[1], Prashant Chandravanshi[2], Suraj Kumar Mukti[3]
[1, 2]*National Institute of Technology Raipur (Mechanical Department).*
[3]*Assistant Professor, National Institute of Technology Raipur.*

Abstract: The aim of this study is to compare various types of coating techniques by highlighting their pros and cons. Due to demand of light weight vehicle, hot stamping process has become most essential process, hence there is an absolute requirement of protective coating to ensure high quality product. This study might help different steel industry to choose the best method of coating steel as per their requirement and availability. High strength/ultra high strength steel sheets are heated up to the temperature about 950^{o} C (so that martensite transformtion can take place)and quickly transferred to forming press. The uncoated steel surface is oxidized and decarburized to a smaller extent (~3 micron) after hot forming. Also the die life is affected by the oxide particles and the formed components has to be cleaned by additional sand blasting process. During hot forging process since the metal is heated upto melting temperature therefore there is always chance to experience LME, which is an undesirable phenomenon. Most common acceptable solution to these issues are to coat the steel with Al-Si coating which is a patented process. This article makes an effort to povide an overview of the different oxidation resistant coating during hot forging of steel, among all the process Al-Si followed by sand blasting is mostly practiced by the automotive industries, while other process are under development. But Al-Sifollowed by sand blasting is an expensive process so to replace this with an economical and effective coating other methods need modification.
Keywords Hot Forging, LME (Liquid Metal Embrittlement), Martensite, Press Forming, GI.

I. INTRODUCTION

"Hot forging is a manufacturing process which is mostly used in automotive industries [2].Hot forming process was patented by a swedish company for manufacturing of lawn mover blades. But due to demand of reduced vehicle weight and high speed this process has become mandetory process in current automotive industries[12].In hot forging process a malleable metal(billet) is shaped by different processes such as hammering, pressing etc. This process is called hot forging because workpiece is heated near to its melting temperature before shaping[13].Hot forging is done in two ways i.e. direct and indirect method. In direct method blank is heated and pressed, the product formed is quenched in the closed tool.In indirect method no heating of blank is done rest steps remains same as direct method"[3].

The utilization of high quality steel sheets to vehicle parts, particularly body-in-white, strikingly expands due to weight decrease. As the quality of steel sheets increments, the formed parts acquire high capacities. Unexpectedly, cold-stepping of the steel sheets is difficult on account of enormous springback ,high stepping load, low formability, short apparatus life and extreme wear, for Suppliers and Factories where it is employed, rankling and seizure. Although ultra-high quality steel sheets having a rigidity of around 1.5 GPa were created cold stepping of steel sheets above 1.2 GPa in rigidity and tensile strength is unpractical. Large springback and low apparatus life despite everything stay as critical issues even if the 1.5 GPa sheets can be cold-stamped. Henceforth, developing processes for creating high quality steel parts above 1.2 GPa are attractive for development in car accident security[29-30].

Hot Forming process is better than other forming process including cold forming superplastic forming because it provide better dimensional accuracy, higher surface profile tolerances, provide uniform thickness of product , resistant to cracking, complex shapes can be easily manufactured and economical compared to other forming process. Besides this steel can be recycled without loss of quality. Hot Forming is used in automotive industries because it allows one to manufacture very thin, complex, strong and light weight but safe components. Due to demand of low fuel consumption and high speed, vehicles are evolved into relatively lighter weight compared to previous era .Lighter weight vehicle consumes less power hence reduces fuel consumption It is used in Volkswagen factory in kassal, M M Forgings Ltd, Ramkrishna Forgings Ltd , National company of industrial vehicles (SNVI) in Rouiba, Peugeot, Hyundai (fifth largest), Nissan, and Fiat[17].

"Hot Forming is hardening process of the formed components in contact with the water cooled dies. High strength/ultra high strength steel sheets are heated up to the temperature about 950^{o} C due to which chances of LME increases. At this high temperature oxidation of heated metal surface takes place as a result of which the quality of product formed is degraded. So we need suitable pre coating so that oxidation process can be avoided.

Widely acceptable solution to these issues are to coat the steel with Al-Si coating, which is a patented as well as expensive process due to post sand blasting process so different industries suggested different coating process. In this article we will discuss all the possible coating techniques employed by different steel industries"[5].These coatings are broadly classified in two categories one is oil based multilayered coating and other is alloy based coating. Both the coating techniques works on basic concept of increasing melting temperature of work piece to avoid LME and at the same time save metal against corrosive oxidation at high temperature[26].

Different coatings used are Zn-Al, Zn-Mn, Zn-Ni, Zn-Al-Mg, TiAlSiN**,** GI, GA(Galvannealed)alloys etc. Oil based(Silane).All alloy based coating have their own pros and cons.

Whereas oil based coating are time consuming but are versatile i.e. available in wide variety. This article presents comparison of different oxidation resistant coating for hot galvanized steel. This study shall be useful for different manufacturer to choose the suitable coating technique as per their convenience. The scope of some coatings may be limited to small scale manufacturing industries [26].

II. LITERATURE REVIEW

According to [41] Journal focuses on understanding the mechanism of the morphological changes and there influences on Al-Si coating, it also focuses on all characterization techniques, including all forms of microscopy and analysis.

1) (Hardell and Prakash, 2008,41) has studies the mechanism of these morphological changes and their influence on the friction and wear characteristics and found that they are unclear and further investigations and analysis are required to explain the mechanism and its role in determining the tribological behaviour.
2) (Hardell and Prakash, 2008,41) has studied that the mechanisms of these changes and their influence on the tribological process are unclear and further studies are required to fully explain these phenomena.
3) (Hardell and Prakash, 2008,41) has reported the actual mechanisms behind the tribological behaviour and the observed morphological changes are still unclear and further detailed studies and analysis are required to investigate the tribochemical layers, as well as the role of surface morphology changes with time, are necessary to get a better picture of the course of this phenomenon.
4) (Hardell and Prakash, 2008,41) has reported that the friction and wear properties of Al–Si-coated high-strength steel during interaction with different tool steels in not sufficient and have not yet been investigated.
5) According to (Ghiotti, 2008,40) other literature studies report preliminary results about the friction coefficient between Al–Si coated blanks and different tool steels as a function of the heating temperature, but either they do not replicate the hot stamping industrial conditions (Hardell and Prakash, 2008) or they do not propose a proper explanation of the investigated phenomena (Hardell et al., 2008).
6) (P. Schwingenschlögl and M. Merklein, 2019,42) has reported that the friction and wear behavior during hot stamping process have not been fully understood yet. Therefore, the tribological conditions within hot stamping are necessary and are investigated in this study by analyzing the influence of workpiece temperature, tool temperature, relative velocity and contact pressure on friction and wear.

III. OBJECTIVE OF THE STUDY

1) Using this article different industries can decide best suitable protective coating as per their requirement and availability.
2) Due to demand of light weight vehicle, hot stamping process is must hence there is an absolute requirement of protective coating.
3) Although most of the coating technique lacks in research but still this study shall be useful to provide basic interpretation of all mentioned coatings.
4) To highlight pros and cons of the below listed coating.

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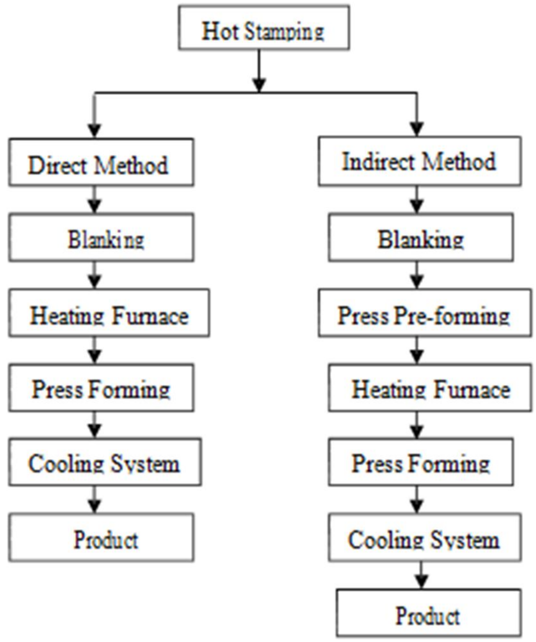
IV. METHODOLOGY



V. METHODS OF OXIDATION RESISTANT COATING

In this article we will be discussing about oil based coating and alloy based coating. Oil based coatings are generally easier than alloy based coatings but are time consuming as well. Out of all alloy based coating Zn-Al alloy is most popular in industrial practices.

A. Oil Based Coating

The presence of the oil (silane) coating resulted in a larger Zn content in the alloy layer formed during austenitization, particularly the austenitized silanecoated GI steel. It is observed that the silane layer helps in avoiding the oxidation and volatilization of Zn, which as a result of which work material retain more [Γ-Fe3Zn10] in the alloy layer. Discontinuous [Γ-Fe3Zn10] patches were observed on the outer part of the alloy layer and did not cause LME tested at 900 °C.Oil based coatings are presented as a promising alternative to hot dip Al-Si coating. These films provide an excellent adhesion to the substrate and a suitable protection against corrosion by creating a chemically inert barrier . LME is absent when a thinner Zn coating (~ 7 microm) is applied, yet imparts cathodic protection to the austenitized silane-coated HDG steel . It is required to check the applicability of different silane based treatments on steel substrates from the point of view of corrosion resistance and adhesion of the subsequently applied organic coating, in comparison with a conventional pre-treatment[1].

This process is still under development but it has potential to come as a promising coating for oxidation resistance during hot forging process. It was observed that silane coating can reduce chances of LME upto 950^{o}C for 5 min [1].To increase the efficiency of the coating and to reduce time this process can be used in combination with GI steel. Zinc is one of the most used protective coatings of steels,because of its role as sacrificial anode and its electro plationg is cheaper.LME is absent when a thinner Zn coating (~ 7 microm) is applied, yet imparts cathodic protection to the austenitized silane-coated HDG steel .Silane coating is known for forming covalent bonds with a metallic substrate , characteristics of both polymeric materials such as flexibility and compatability. Hence it can be used on GI Steel for getting better dimensional accuracy.The In this method first a blank is galvanized(not necessary) then a thin layer of oil A is applied to it.Strong barriers having oxidation resistant boundaries are created on the surfaces of the sheets by drying the covered sheets with the oils, and the film changes into melted barriers having an obstruction of oxygen at raised temperatures.Then the same process is repeated with oil B.The sheets dried after the ultrasonic cleaning are covered with the oil by methods for are warmed in the electrical heater acclimated to an ideal temperature, and afterward are normally cooled.

This process is repeated 3 times to enhence efficiency of coating. Finally hot stamping process followed by quenching is done.Oxide layer formed on the surface of coating is then removed by 10% conc. Phosphoric acid heated at 70 C. €Finally, Steel is ready for use[1].The schematic of process is shown in fig.1, [1].

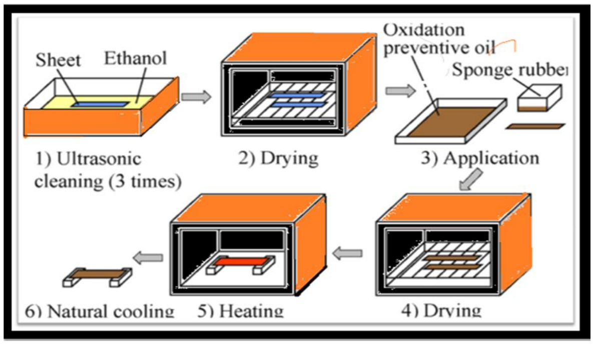


Fig 1. schematic of oil coating[1].

Table 1. Composition of Oil A and B.

Oils	**A**	**B**
Composition	Boric Acid solid lubricant, Fatty acid soap, sequestering agent.	Oil based fatty acid soap, boric acid and phosphate solid lubricants, Metallic soap, sequestering agent.
Density	1115.5 kg/m^3	1.1180 kg/m^3
pH	10	10.41

1) Suppliers and Factories where it is Employed

a) Condat supplier [19].

b) JASO, ACEA, SAE (for Al only) [20-22].

2) Features

a) Surface roughness depends on feed rate and type of oil used. Surface roughness for low quality oil is also very less for oil coating compared to alloy coating[1].

b) Small patches of phosphoric acid are observed on the work piece [1].

3) Merits

a) Versatile i.e. can be used with work piece like steel, Al, Yellow metal, special alloys used in industries such as aeronautics and Medical [19].

b) Available in wide variety and forms such as very high temperature greases, HFC hydraulic fluid [19].

c) Ecofriendly and bio-degradable [19]

d) Can work with metals having high melting point greater than 1500^oC [19].

4) Demerits

a) A phosphate layer got deposited on work piece which degrade its mechanical properties [24].

b) Time consuming and lengthy [24].

c) Process is very sensitive towards the mode of heating used i.e. Electric heating, Induction heating and Furnace heating. Ideally induction heating should be used [24].

d) Not very effective in oxidation resistance for single layer coating [24].

e) Chances of crack development on metal substrate [24].

f) Crack propagation through the substrate is always there for single layer coating [24].

B. GI and GA alloy Based Coating

Galvanized and Galvannealed steel are permanent coating unlike oil coating. These are single layered coating. Fe-Zn reaction layer improves the melting point of hot dip galvanized steel strip after press hardening process. Zn rich phases appear brighter than iron rich phases. But these coating suffers diffusion phenomenon. In diffusion electrons of heavy element reinflect more than the lighter ones.Zn is known for its corroion resistant property especially against red corrosion products due to intense internal heating during austenization the iron content of the mixture is drastically increased[24-25].

Being economical and simple coating technique this method is widely practiced in industries.This is commonly employed in most of the coating technique such as Al-Si, Zn-Mn etc.Zinc-covered hot forged steel sheet utilized for the creation of solid, corossion resistance is important to the car industries, yet worries about liquid metal embrittlement (LME) remain. In particular, cracking related with LME, through better comprehension of the alloyed covering microstructural highlights and association with the substrate sheet during misshapening, is desired[26],[25].

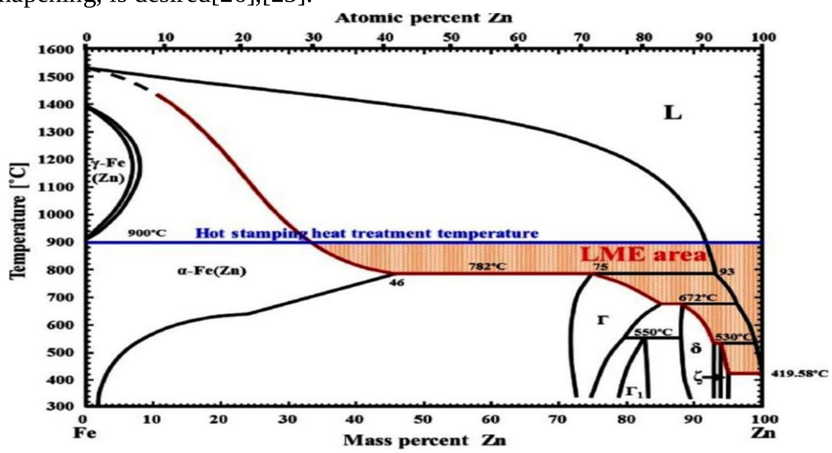


Fig.2 Fe-Zn binary phase diagram [28]

1) *Suppliers and Factories where it is Employed*
a) Thyssenkrupp-steel [25].
b) US STEEL [24].
c) XT BOLTS [23].
d) JFE steel corporation [32].

Table 2. Products and characteristics of JFE

Coating	Product	Characteristics
Pure Zn	JFE GALVAZINC	Zinc coated by hot dip galvanizing. Light coated products have good weldability and formability. Usable from general processing to deep drawing according to application. Heavy coated products have superior corrosion resistance. Wide application are possible by selecting spangle or a post treatment.
Pure Zn	JFE GALVAZINC ALLOY	Zn-Fe alloy coated by hot dip galvanizing and annealing. Zn-Fe coating has superior paint adhesion and corrosion resistance. Weldability is superior to JFE GALVANIZING products.
Alloy	ECOGEL-Neo	ECOGAL-Neo is a Zn-5% Al-based alloy-coated steel sheet, which realized higher corrosion resistance than conventional Zn-5% Al alloy-coated steel sheets by adding small amounts of magnesium (Mg) and nickel (Ni) to the Zn-5%Al alloy-coating. A high corrosion resistance chromate-free conversion coating is also applied. In addition to excellent corrosion resistance, the coated layer has good adhesion and ductility, securing excellent formability. Beautiful external appearance enables use in applications without painting.
Alloy	GALVALUME STEEL SHEET	Alloyed coating containing zinc and about 55 % aluminum. Products have heat resistance and heat reflection property of aluminum in addition to corrosion resistance of zinc and aluminum,

2) Features

a) Little Al is added which hinders Zn evaporation and form Al_2O_3 which is passive hence reduce oxidation i.e. Al is just in case of GI and GA [24].

b) Thickness of coating initially is 17 micrometers which consists of three layers which are Fe-Zn Intermetallic Fe-Zn solid solution and metal oxide (for suppressing Zn evaporation) [24].

c) Zn evaporates when heated above 600^{o}C (this is only observed under inert atmospheric condition) [24].

d) GA-Hot deep pure zinc heated up to 480^{o}C-520^{o}C, is better than GI. In this process Fe is replaced by Fe-Zn intermetallic compound which has higher wedability, hardness, ductility, shiny appearance [24].

3) Merits

a) Best metallic appearance than any other coating [24].

b) Excellent cathodic corrosion protection [24].

c) Pentability, wedability increases drastically [24].

d) Excellent cosmetic corrosion protection, perforation corrosion protection but limited cathodic resistance at temperature above 600^{o}C [24].

e) Superior in terms of cost and life cycle [24].

4) Demerits

a) The surface must be cleaned initially otherwise chances of oxidation increases [24].

b) Problem of LME can't be removed completely by Zn alone [24].

c) Adhesion to Fe-Zn coating is poor at high temperature hence low corrosion resistance [24].

d) Cracks can propagate towards metal substrate very easily [24].

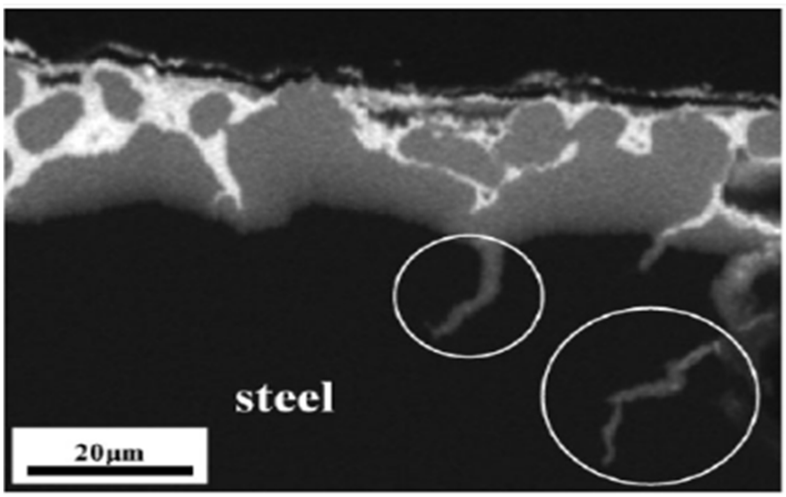


Fig.3 Propogation of crack when GI steel is heated upto 850^{o}C for 5 minutes[26].

C. Al-Si Coating followed by Sand Blasting

This is the most widely used technique which is a temporary coating. The aluminized (Al 10 mass% Si) coating on hot stamped steel is used in commercial applications. The effect of temperature on microstructure and formability of the Al 10 mass% Si coating was investigated at different temperatures and it was observed that on increasing temperatures hardness of coating is reduced and cracks propagation takes place. As temperature reaches near melting temperature Fe content increases and the Fe-Al-Si ternary phase transforms into Fe-Al binary phase [7].

This coating is provided before pressing and heating. The coated work piece is first shaped by hot forging process and then quenched. The oxide layer on the surface of work piece is then removed by sand blasting process. Sand blasting process is a cleaning process in which small spherical balls of iron is collided with work piece surface. Finally work piece is cleaned by normal water and the work piece is ready to use [5]. The Al-10 mass % Si coating was mostly comprised of intermetallic phases. At 870^{o}C, the temperature was higher than the melting points of Al 10 mass % Si coating (577^{o}C) and Fe_2SiAl_7.It is observed that there was no crack formation at 1050^{o}C, at the same time Fe_3Al and FeAl shows great resistance against oxidation [7].

VI. SUPPLIERS AND FACTORIES WHERE IT IS EMPLOYED

GM Global Technology Operations LLC General Motors Co patented process [37].

A. Features

1) Many cracks observed after heating at temperature 870, 900, 930°C for 5 minutes (cracks started from coating surface and stopped at substrate coating interface i.e. doesn't reach steel substrate) [33].
2) After heating at 1050°C for 5 minutes no cracks at outer and inner layer are observed [33].
3) Once pre-coat is heated forms 40 micrometer layer of Al-Si-Fe [34].
4) Time for which coating specimen is heated influences the diffusion which affects quality of product [34].

B. Merits

1) Excellent formability (due to formation of Fe_3Al and FeAl) [33].
2) Inert atmosphere within the furnace is not compulsory [34].
3) Work piece wear is comparatively lower than Zn-Ni [35].
4) Al-Si shows adhesive wear behavior which is less harmful as compared to abrasive wear behavior [35].

C. Demerits

1) Fe_3Al and FeAl formation reduces hardness of coating [33].
2) Coating hardness decreases with increase in heating temperature [33].
3) Not suitable for indirect hot stamping [34].
4) Melting temperature of Al-Si alloy is lower than temperature required for hot stamping as a result adhering of molten coating occurs [26].
5) Surface roughness is very high (Jaggis are visible clearly), Needle like spots are also visible [35].

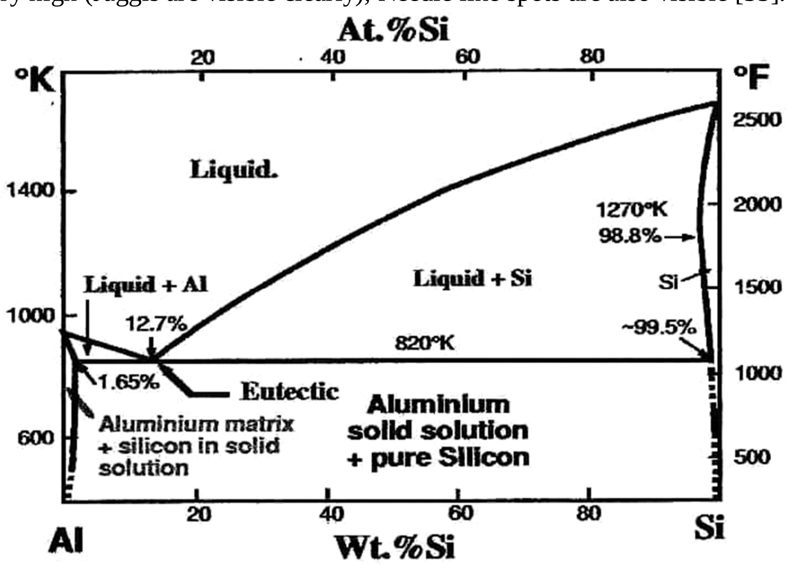


Fig.4 Al-Si phase diagram and different phase reactions [29].

Table 3. Comparing features of above mentioned coatings [29].

	Non- Coated	Al-Si Coated	Zn Coated
Heating Time	2-3 min	5-6 min	4-5 min
Tool Wear	large wear by oxidation	Predominantly adhesion	Predominantly abrassion
Scale removing	Shot Blasting	Unnecessary	Unnecessary

VII. ZN-MN ALLOY BASED COATING

This work demonstrated that it may be possible to use other elements to form high melting temperature compounds with Zn to prevent corrosion at higher temperature. Reduction of chemical diffusion during heat treatment could be achieved due to the presence of a solid coating for a longer time. This characteristic could reduce the formation of inter diffusion Just like Al in galvanized coatings the alloying of Zn with an element with high affinity to oxygen such as Mn may permit to form an oxide layer on the surface of the heat treated coating. The study of the performance of new Zn-Mn coating materials compared to commercial products has been done but this process is under development [14-15].

The aim of this work is that it may be possible to use other elements (Mn & Co) to form high melting temperature compounds with Zn to prevent corrosion at high Temp. Higher Mn content in Zn-Mn coating increases melting temp. Hence it can prevent LME at higher Temp. Being element with high affinity to oxygen, Mn forms an oxide layer on the surface of the heat treated coating and reduce the loss of Zn by oxidation or evaporation. It is possible to modify the process because Zn-Mn alloy with higher Mn content can be used with other pre coating to enhance coating efficiency [14-15].

A. *Suppliers and Factories where it is Employed*

1) Patented by Vijay Jagannathan Townsend, Nippon Steel Corp[39].
2) Kawasaki Steel Co [39].

B. *Features*

1) Diffusion can be avoided as coating liquefies at very high temperature [15].
2) For composition Zn-29 % Mn, theoretically evaluated melting temperature is 800^{o}C [15].
3) For composition Zn-40 Mn, liquid phase of alloy can be avoided till 900^{o}C [15].

C. *Merits*

1) Zn-Mn provides better corrosion protection compared to GI [15].
2) LME during hot forming is less compared to GI [15].

D. *Demerits*

Coating may not bear high temperature in oxidative environment due to formation of MnO (i.e. low Mn content) and Mn let go the coating to higher temperature ranges. According to [15] it was reported that actual scenario about Zn-Mn coating is still not clear [15].

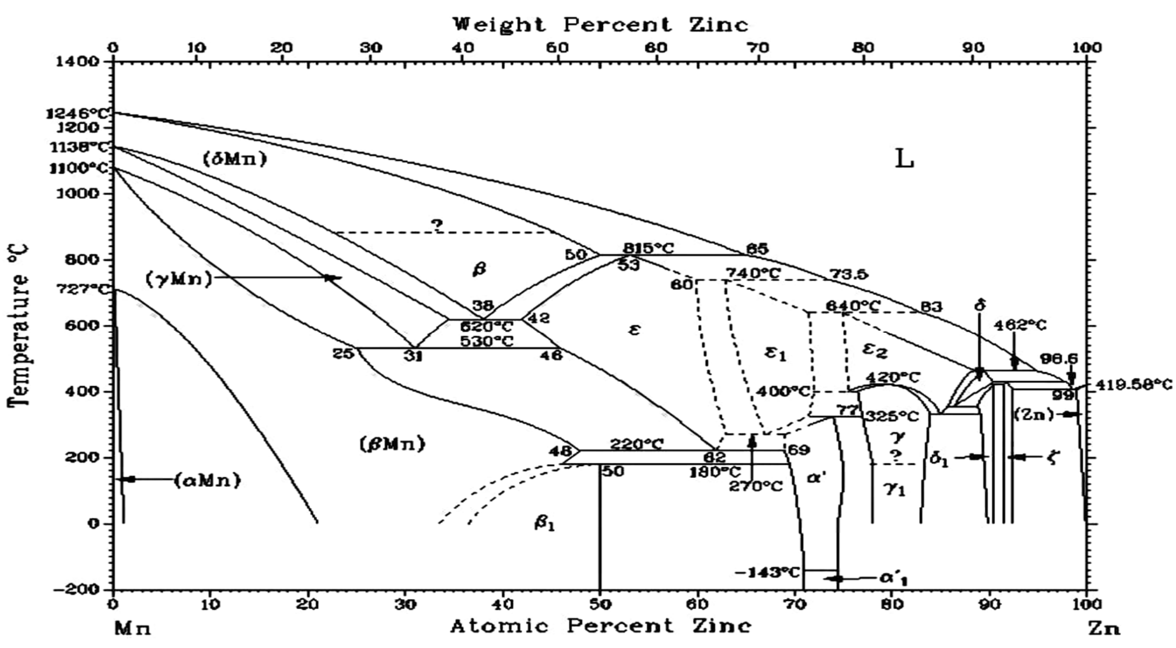
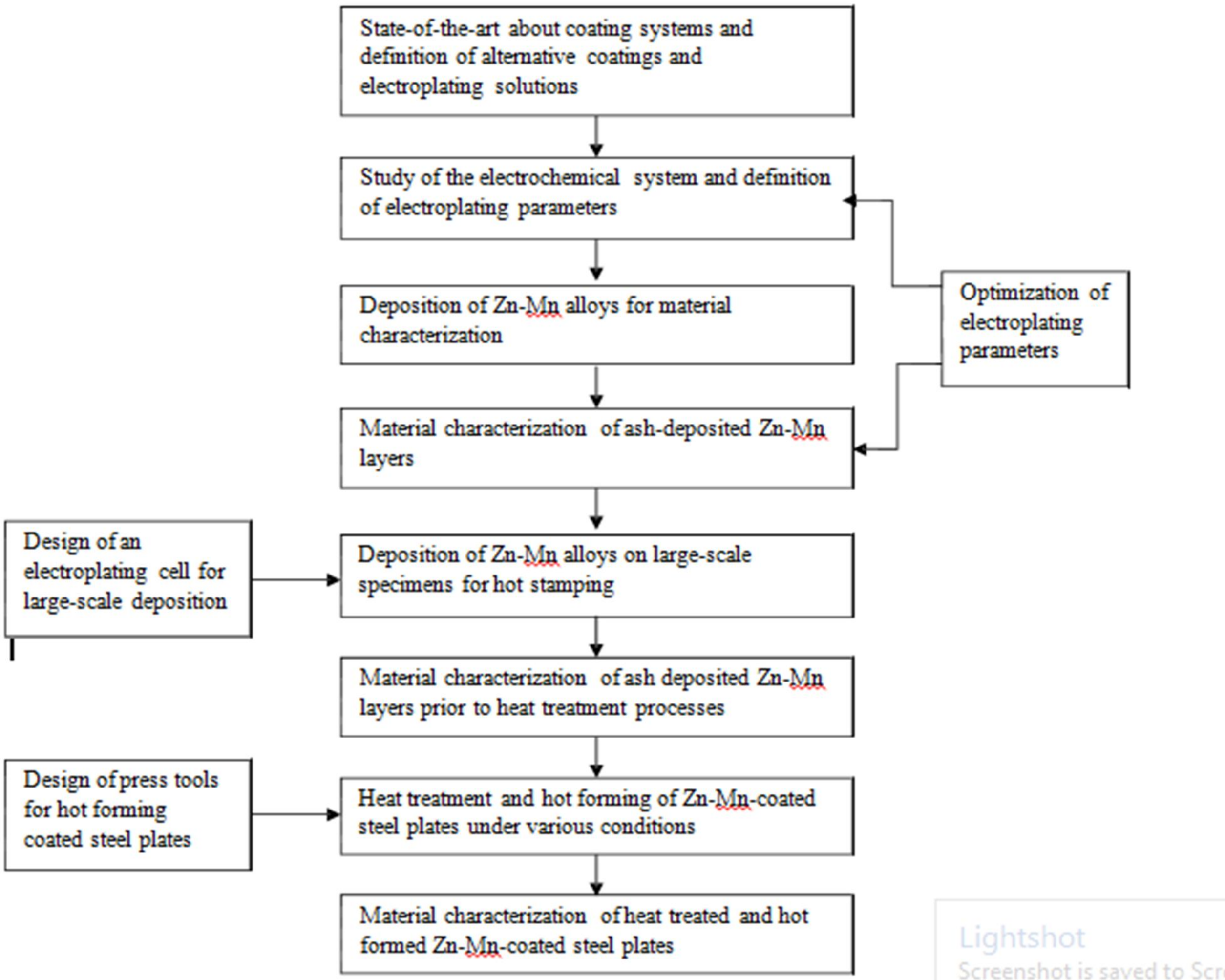


Fig.5 Mn-Zn equilibrium phase diagram[14-15].

Table 4. Zn-Mn coating on hot formed steel parts [14-15].



VIII. ZN-NI ALLOY BASED COATING

Zn-Ni alloy works on the principle similar to Zn-Mn i.e. doping high melting temperature elements with Zn so that melting temperature of alloy may increase. This will reduce Zn evaporation and LME which was present in case of GI and GA. The more commercially attractive composition of Zn-Ni alloys comprises from 10 % to 15 % Ni (in mass) [28].

Elective coatings, for Suppliers and Factories where it is employed, electroplated Zn-Ni, have been under scrutiny to assess their potential for substitution of Al-Si coatings, so as to stay aware of the high anticipated world interest for this sort of steel7. Zinc-based coatings are profitable nearly to the Al-Si since they give cathodic assurance to the steel substrate though the component of insurance of Al-Si coatings against corrosion is by barrier[28].

A. Suppliers And Factories Where It Is Employed

1) Holzapfel Group [38].

B. Features

1) Appropriate reduction of Ni content reduces material cost [26]
2) Strength of oxide layer up to (3.9±1) GPa can be obtained [35].
3) Wear behavior is abrasive in nature [35].
4) Higher the Zn content more will be the corrosion resistance [26].

C. Merits

1) It has high thermal stability hence most suitable for hot forming [27].
2) Wedability of Zn-Ni alloy is greater than GA and GI [26].
3) Hardness and melting temperature of coating is very high (about 875°C) [26].
4) Very smooth surface finish is obtained compared to Al-Si [35].
5) Both direct and indirect forging is possible [31].
6) These alloys show high corrosion resistance, formability and wedability [28].

D. Demerits

1) In long term its corrosion resistance is poorer than GI and GA [26].
2) Material cost of Zn-Ni alloy is higher due to presence of Ni [26].
   a) Work piece wear is higher as compared to AlSi
   b) Low melting temperature[26].
3) Poor wetting performance[26].[35].

IX. OTHER ALLOY BASED METHODS

Alloys such as Zn-Al, Zn-Al-Mg TiAlSiN Nano Composite Coatings etc. are based on same principle as Zn-Mn alloy based coating i.e. it also increases the melting temperature of work piece by alloying metal with higher melting temperature than work piece, so that LME (Liquid Metal Embrittlement) can be eliminated at the same time it is desired to choose alloying metal with lesser affinity towards oxygen at high temperature. All these alloys have different ways of application, most of them are applied by electroplating process and melting process, but some are applied only by ion-deposition method. Since it is generally electroplated hence it is permanent coating [5-9]. After hot forging process the work piece along with coating material undergo quenching process. Quench hardening is a mechanical procedure where steel and solid metal composites are fortified and solidified. These metals comprise of ferrous metals and combinations. This is finished by warming the material to a specific temperature, depending upon the material. This delivers a harder material by either surface hardening or through-hardening differing on the rate at which the material is cooled. The material is then frequently tempered to lessen the fragility that may increment from the quench hardening process. Things that might be quenched incorporate apparatuses, shafts, and wear squares. Prior to hardening, cast steel and iron are of a uniform and lamellar (or layered) pearlitic grain structure. This is a blend of ferrite and cementite formed when steel or solid metal are produced and cooled at a moderate rate. Pearlite isn't a perfect material for some basic utilizations of steel compounds as it is very delicate. By warming pearlite past its eutectoid change temperature of 727 °C and afterward quickly cooling, a portion of the material's precious crystal structure can be changed into a lot harder structure known as martensite. Prepares with this martensitic structure are regularly utilized in applications when the work piece must be exceptionally impervious to deformation, for Suppliers and Factories where it is employed, the front line of cutting edges [13].

This coating is known for its high hardness and low coefficient of friction. It was earlier used in coating of cutting tool material but it is also proved as remarkable coating against oxidation of hot deep galvanized steel. Its basic principle against oxidation is same as other alloy but the way it was applied is different. It was earlier applied by plasma arc and magnetron sputtering, but it is now applied by using ion beam deposition. The only Demerits of the coating is that the surface roughness is very high due to which it lacks its role as a permanent coating in large scale industries [9].

Composition used is Silicon (4.1 at. %), Amorphous Si_3N_4(14.5 at. %) this composition is shown when 101.4 electron volt (SiN bonding) is shown. The composition of Si_3N_4 varies as the bond strength changes. Si_3N_4 is the key to enhance oxidation resistance of these nano-composite coating [9]. All these alloys are still under investigations but we are enlisting Suppliers and Factories where it is employed merits and demerits of Zn-Al-Mg only [9].

A. Suppliers and Factories Where is Zn-Al-Mg Employed

Currently used in Tata steel in the name of magizinc [36].

B. Merits Zn-Al-Mg

1) Better corrosion resistance compared to GI and GA coatings [26].
2) LME can be avoided completely [26].
3) Excellent cathodic protection up to 350-375°C [26].
4) No loss of strength as in case of GI [26].

C. Demerits Zn-Al-Mg

1) Cracks formed may reach to substrate at required hot stamping temperature [26].
2) Low melting temperature [26].
3) Poor wetting performance [26].

Table 5. Major merits and demerits of various coatings[27],[26].

	Al-Si	GI	GA	Zn-Ni	Hybrid Coating	Zn-Al-Mg
Merits	Good oxidation resistance, no need for phosphating	Best cathodic corrosion resistance	No LME, good cathodic corrosion resistance.	Higher melting temperature, no LME	Good cathodic corrosion resistance	Excellent cathodic corrosion protection, no LME, (used in the name of Magizinc).
Challanges	Requires shot blasting Coating brittleness liquid Al adhesion.	LME liquid Zn adhesion oxides removal brittleness of coating.	Brittleness of coating	Expensive	Formation of brittle Fe-Al intermetallics, melting of Al and Mg, Higher cost.	Hydrogen uptake can occur in this coating.

X. CONCLUSION

This article makes an effort to povide an overview of the different oxidation resistant coating during hot forging of steel, among all the process Al-Si followed by sand blasting is mostly practiced by the automotive industries, while other process are mostly under development.One can use different permutation and combination of these coating to make even better oxidaion resistant multilayered coating.Out of all the coatings oil based coating is temporary coating which is finally cleaned by hot conentrated phosphoric acid but still it is not popular among industries due to lack of expermental analysis.Al-Si is followed by sand blasting hence it is expensive so to replace this with an economical coating other methods need modification.This comparative study shall help automotive industries to choose the desired coating according to their convenience.The main issue during hot forging while using still is LME which can be completely avoided by using any of the coatings discussed in this article.

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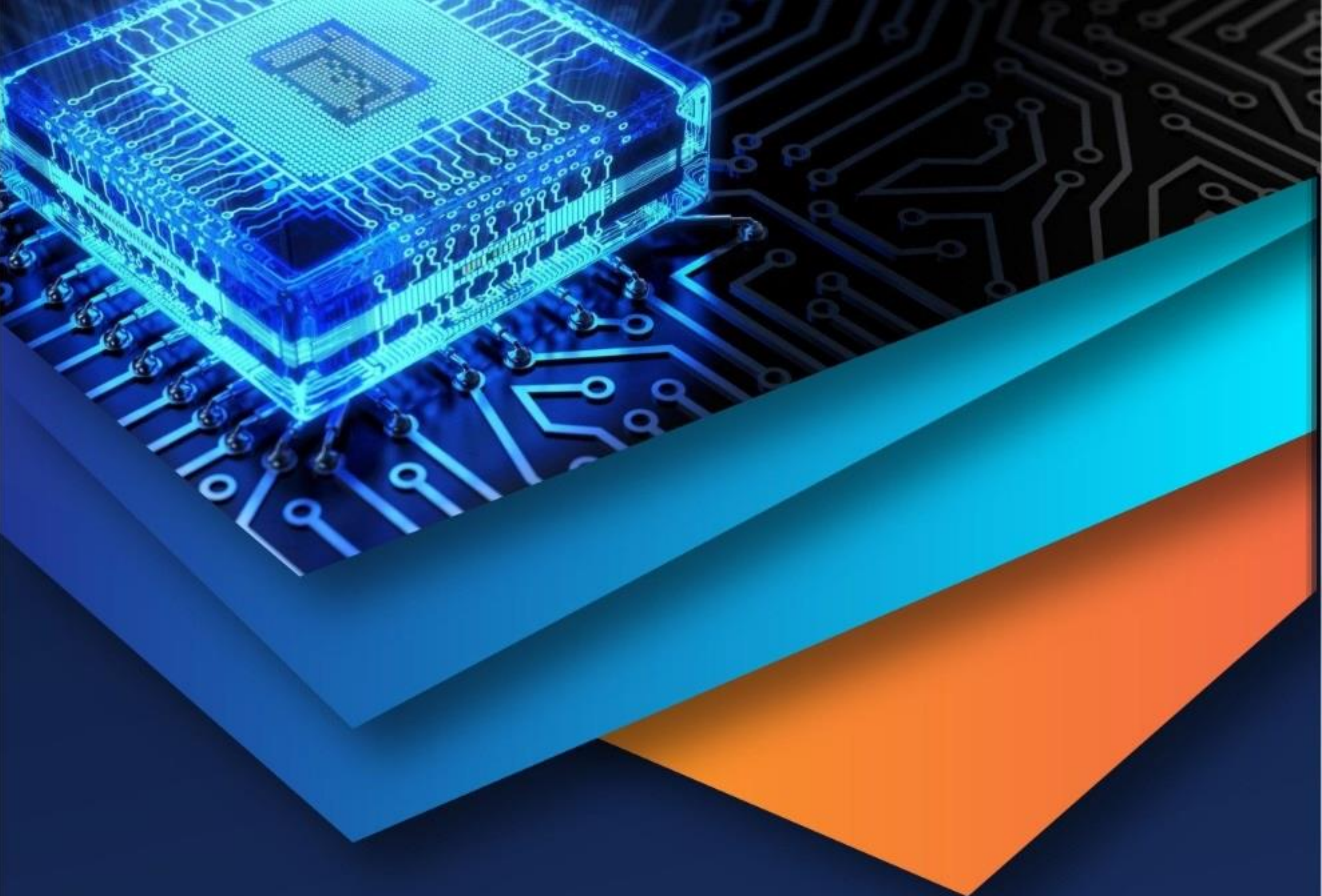

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