Research on Elements Distribution in Hot Dip Aluminum Silicon Coating of Hot Stamping Steel

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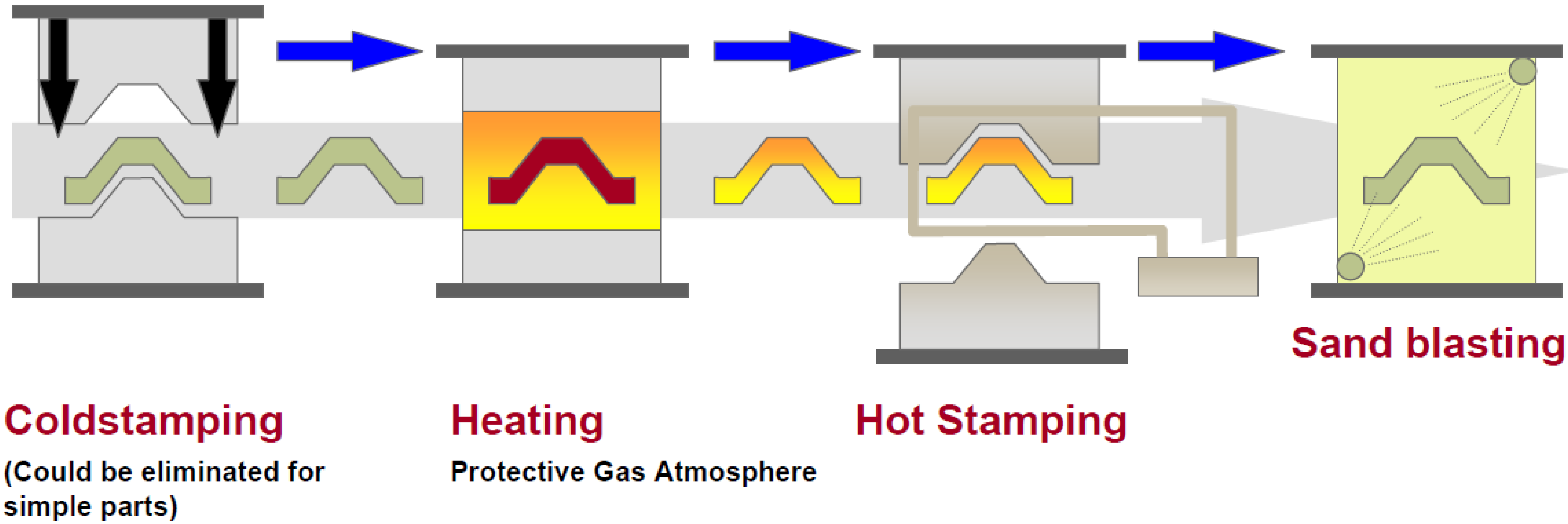
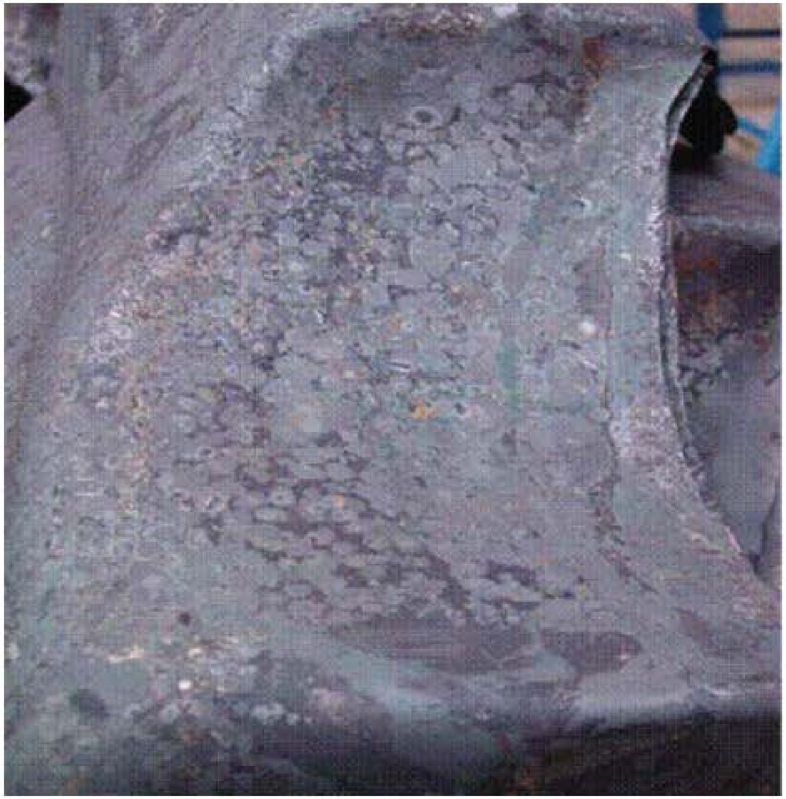
1.Introduction

Why do we need coating on hot stamping steel?

Indirect process for uncoated 22MnB5 (complicated parts)



None coating

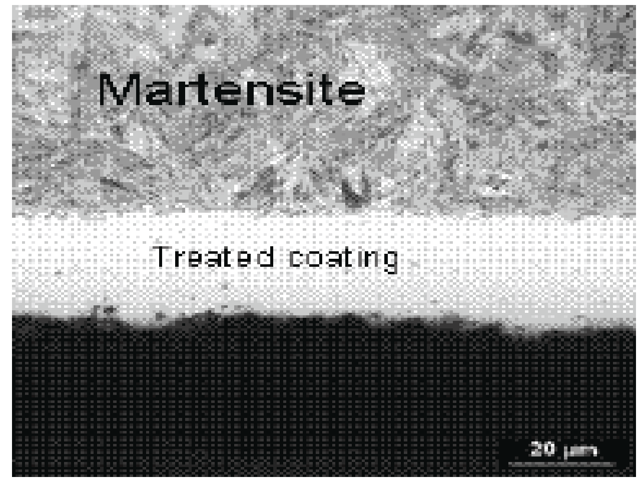


Al-Si coating

Basic property of Al-Si coating

Aluminized coating has advantage as follows:

- to be resistant to high temperature oxidation
- Without dephosphorization
- corrosion resistant
- a high level of reflectivity.



Aluminized coating has disadvantage as follows:

- Sticking to ceramic roll in calefaction process
- crack-sensitive deformation temperature at 700-800℃
- Increasing production cost

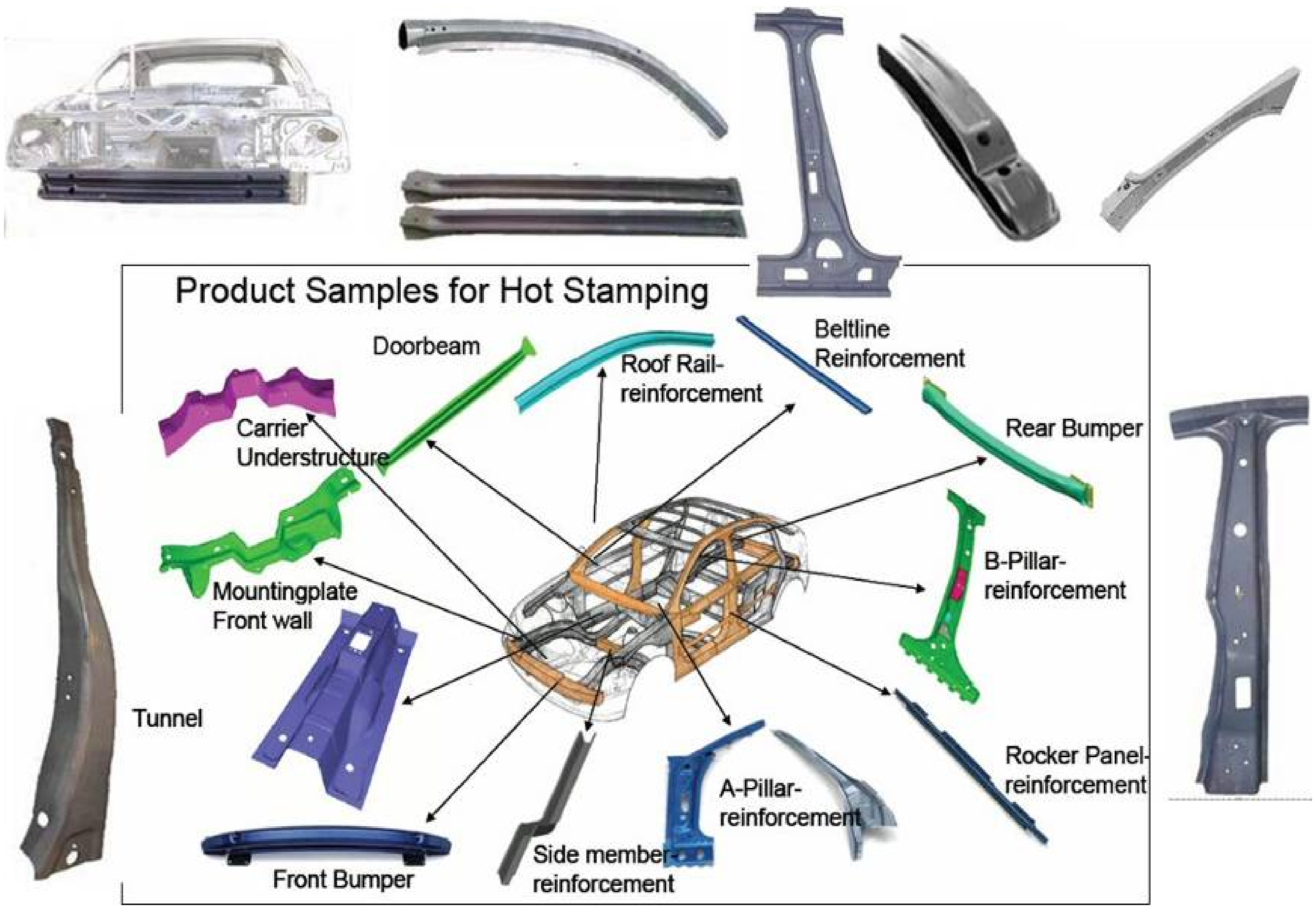
Basic property of Al-Si coating

(1)Al-Si alloy, of which **heat resistant property** is equal to 409 stainless steel, has a brightness appearance on temperature below 450℃, and its color changes when temperature is over 500 ℃.

(2) Al-Si alloy could be used as **surface protection material** on hot stamping, which could avoid creating Fe oxidation on hot stamping steel surface during calefaction or hot stamping. And Fe oxidation scraping dies can also be avoided, leading to reduce later dephosphorization process.

(3) Al-Si alloy could be used to make worm wheels, aeroengine and so on， and plays an important role in high temperature anti-oxidation and anti-corrosion.

Applications



Patents of Hot Dip Aluminum Silicon Coating of Hot Stamping Steel

Patent	Coating	Producer
USIBOR-AS	Al-Si	Arcelor-Mittal
USIBOR-GI	GI	Arcelor-Mittal
USIBOR-GA	GA	Arcelor-Mittal
WO2005021820 A1	Zn	Voestalpine
EP2045360 A1	Al-Si + Zn	ThyssenKrupp
US7867344 B2	Al-based or Zn-based	Nippon

2. Experiment methods

Coating material: **Al-10%Si**

Element composition [wt%] of experiment steel

Element	C	Si	Mn	P	S	Al	B
Content	0.22	0.25	1.35	≤ 0.01	≤ 0.01	0.03	≤ 0.003

Samples: 2mm*120mm*220mm

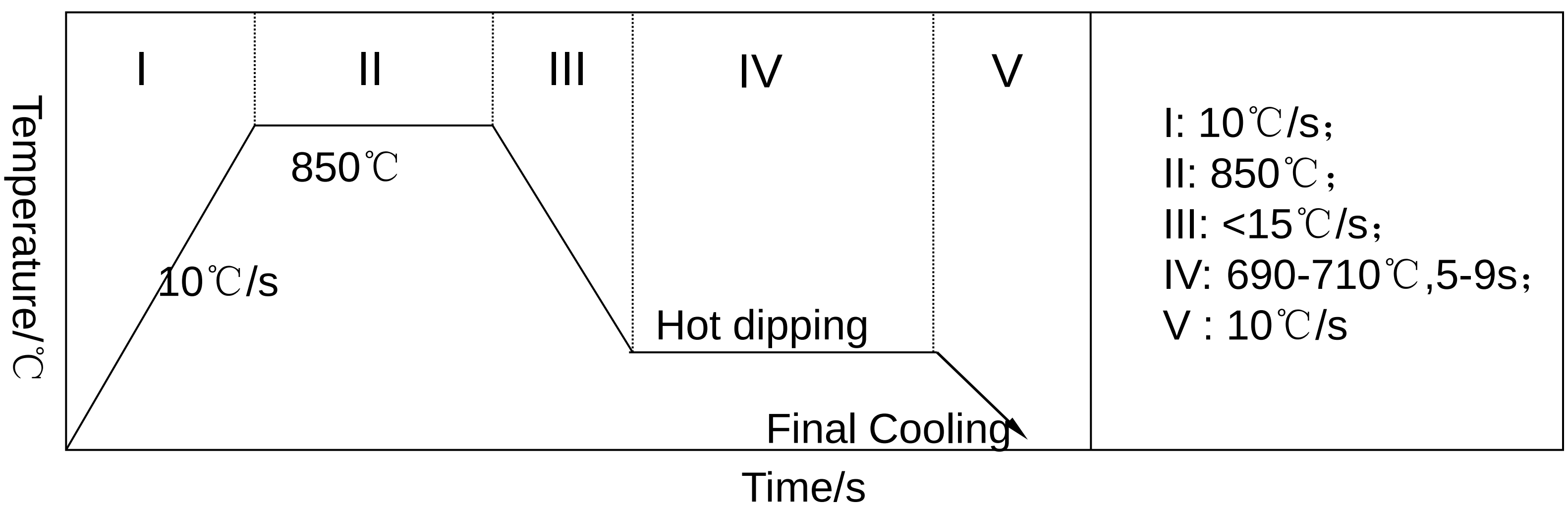
pickling → degreasing → rinsing → drying

→ Hot dipping → Coating analysis

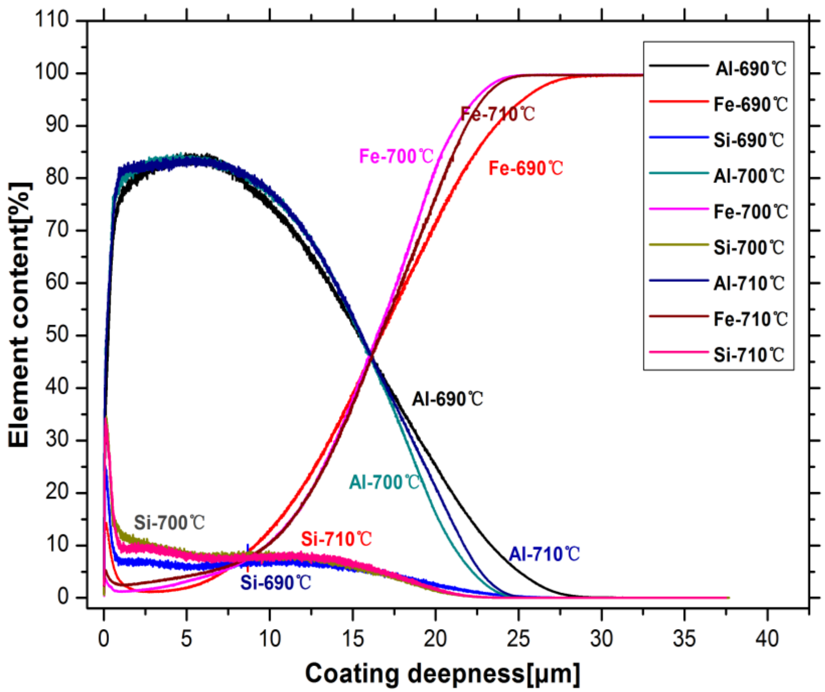
- GDS
- SEM
- XRD
- Stamping

Annealing and hot-dipping process parameters : heating up rate 10℃ /s, heating temperature 850 ℃, hot-dip temperature 690℃, 700℃, 710 ℃, hot-dip time 5s, 7s, 9s, coating cooling rate 10 ℃ /s.

hot dip simulator

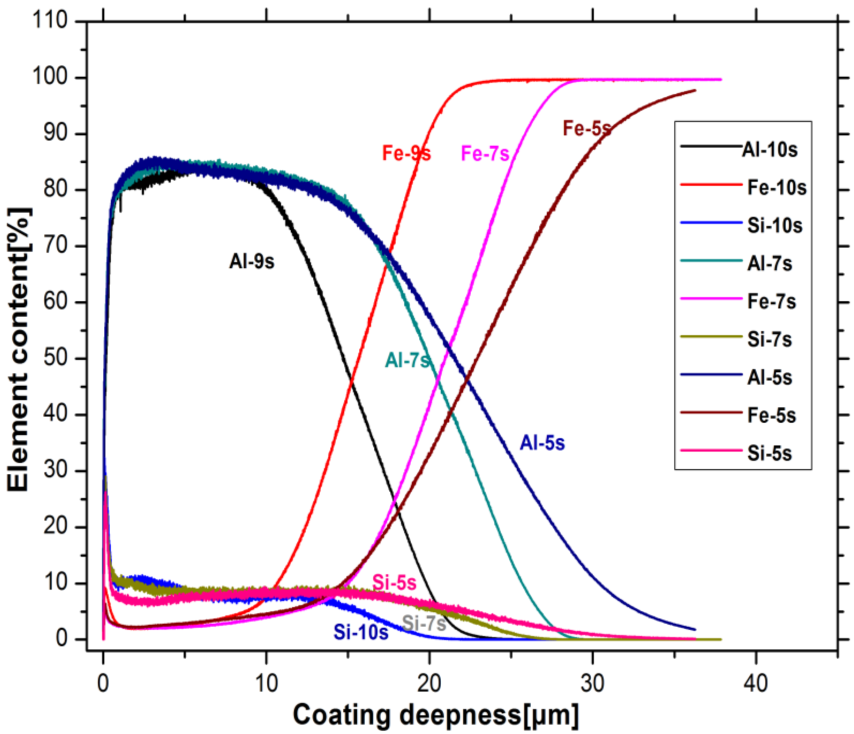


3. Results and discussion



(1)Al content decreases slightly form surface to 10μm depth coating, and decreases dramatically with coating deepness increasing from 10μm to basic steel.
(2)Si content decreases slightly with coating deepness increasing on the whole, and is distributeed comparatively stable by contrast to Al and Fe element , only decreases dramatically in the coating approaching to basic steel.
(3) Fe content increases with coating deepness increasing.

The relationship between hot dip temperature and element distribution in coating (hot dip time 10s)



(1)hot dip time has obvious impact on element distribution in coating from coating surface to basic steel.

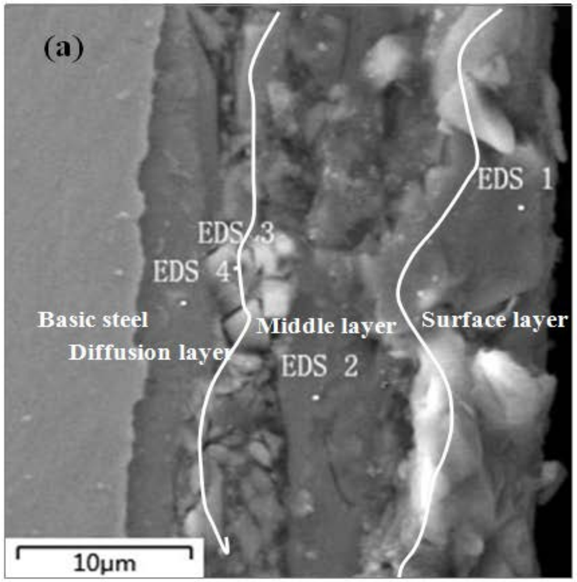
(2)Firstly, Al and Fe content is almost the same, and Si content is slightly different in the coating with different hot dip time (5s, 7s, 9s), with coating deepness increasing from coating surface to 10μm.

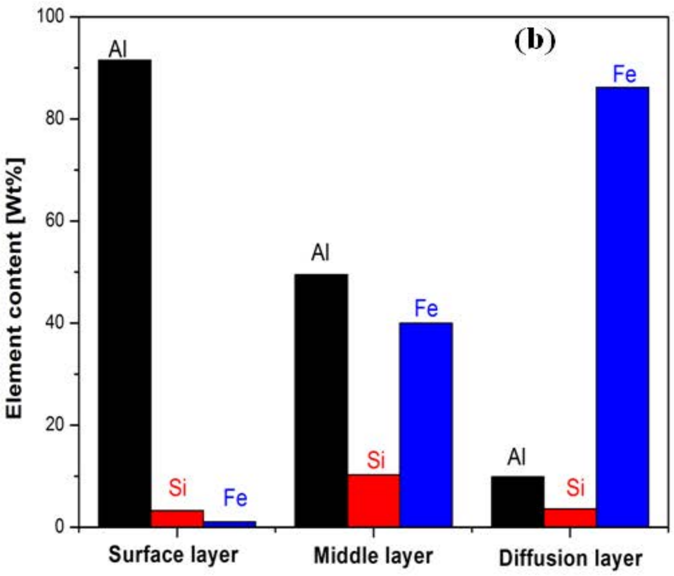
(3)Secondly, hot dip time has distinct impact on element content in coating from 10μm to basic steel, Al and Fe content increases, Si content decreases with hot dip time increasing.

The relationship between hot dip time and element distribution in coating(hot dip temperature 700℃)

Element content in different depth coating/%

Hot dip time/s	Coating depth [μm]														
	5			10			15			20			25		
	Al	Si	Fe	Al	Si	Fe	Al	Si	Fe	Al	Si	Fe	Al	Si	Fe
5	83.91	7.03	2.94	80.65	4.47	9.24	76.15	7.99	10.92	57.31	**6.63**	33.05	32.56	**3.42**	62.72
7	84.56	8.79	2.15	80.03	7.43	7.91	77.41	8.15	10.11	49.82	**5.65**	42.03	14.02	**1.15**	84.23
9	83.06	8.66	2.68	79.15	8.61	7.48	47.56	5.96	43.75	8.69	**0.52**	90.47	0.06	**0.002**	99.62





SEM microstructure and element distribution in Al-Si coating(a)SEM microstructure(b)element distribution

Energy spectrum analysis results of every coating layers

Energy spectrum	Element content[wt%]				Element content [Mol%]				Al:Si:Fe auto unit ratio	Phase
	Al	Si	Fe	O	Al	Si	Fe	O		
1	91.5	3.3	1.1	4.1	89.59	3.12	0.52	0.07	28.75:1:0.17	$(\alpha+\beta), Al_2O_3$
2	49.5	10.3	40.0	0.2	62.61	12.56	24.40	0.01	4.98:1:1.94	$Fe_XAl_YSi_Z$
3	51.7	9.8	37.0	0.5	65.98	10.62	22.34	0.01	6.21:1:2.10	$FeAl_3$（Si）
4	9.9	3.6	86.2	0.3	17.86	6.26	74.97	0.01	2.85:1:11.97	$Fe_XAl_YSi_Z$

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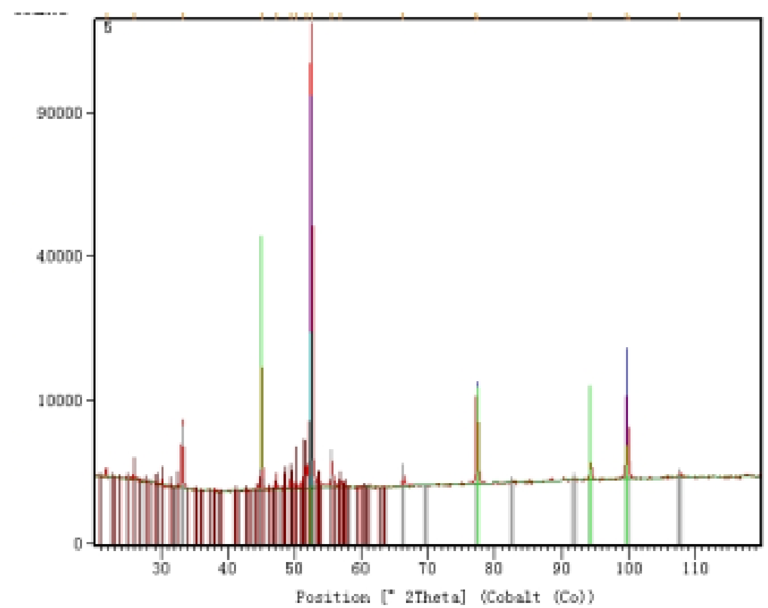
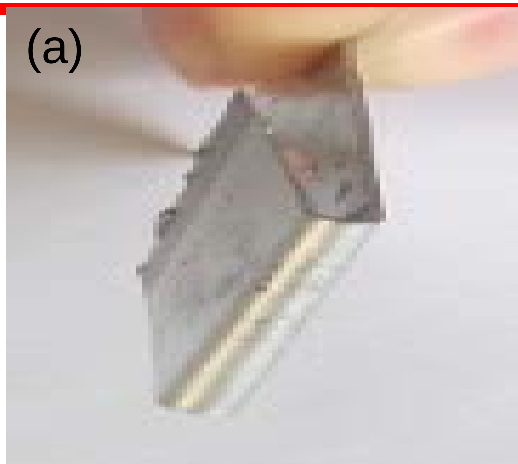
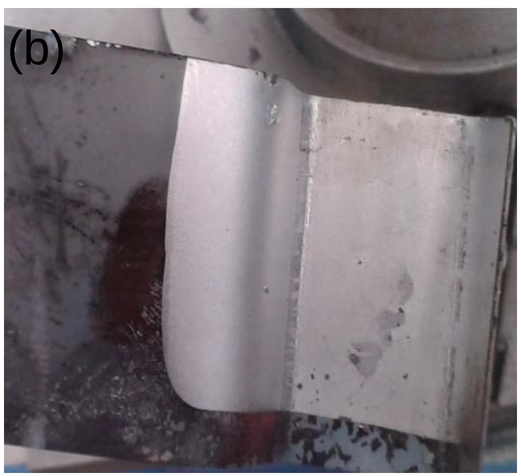
Basic physics character of phases in Al-Si coating

Element/Phase	Density[g/cm3]	Melting point[℃]
Al	2.6984	660.1
Si	2.329	1412
FeAl3	--	1330
Al15Fe3Si2	--	860
Al5FeSi	--	870

XRD phase analysis of Al-Si coating







Al-Si coating stamping piece
(a)Cold stamping
(b)Hot stamping at 850℃

(c) Stamping machine
(d)Die and mould

4. Conclusions

(1) Fe content increases with coating deepness increasing. Al content decreases slightly form surface to 10μm depth coating, and decreases dramatically with coating increasing from 10μm to basic steel. Si content decreases slightly with coating increasing on the whole, and the distribution is comparatively stable by contrasting to Al and Fe element， only decreases dramatically in the coating approaching to basic steel.

(2) Hot dip temperature has no obvious impact on element distribution in coating, but has some impact on Si content in surface coating. With the hot dip time increasing, Al content decreases, Fe content increases, and Si content decreases.

(4) Al-Si coating is composed of 3 layers, surface layer contains fine and close Al_2O_3 film, which has good high temperature anti-oxidation property and hot stamping property, middle layer contains high melting point phase ,such as rich Fe phase , $FeAl_3$,which has excellent high temperature anti-oxidation property. The elements in diffusion layer can even be transited to basic steel, so coating has good adhesion property.

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Thank you!