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Interface properties and phase formation between surface coated SKD61 and aluminum alloys

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Abstract: The intermediate phase formation and surface protection effects between SKD61 die mold alloys and aluminum alloys were investigated during a simulated die-casting process. The surface coatings of SKD61 alloy were carried out via Si pack cementation coatings at 900 ℃ for 10 h and the ε-FeSi phase formed. When the coated SKD61 alloy was dipped in the liquid aluminum alloy (ALDC12), the surface coated SKD61 alloys showed better surface properties compared with uncoated SKD61 alloys, i.e., the intermediate phases (FeSiAl compound) were not produced for the coated SKD61 alloy. The coating layer of ε-FeSi served as a diffusion barrier for the formation of FeSiAl compounds.

Key words: die-casting; surface protection; diffusion pack coatings; SKD61 alloy

1 Introduction

High pressure die-casting has been one of the well-known casting methods for aluminum alloys, and numerous studies have been reported in order to optimize the casting speed and obtain defect-free fabrication of aluminum castings during repetitive casting process [1−5]. In order to carry out a successful casting process, materials selection for a casting die mold is one of the critical factors from efficient and cost-effective points of view[2−5]. One important material for the casting die mold is SKD61 alloy that is one kind of stainless steel.

It has been documented that one critical factor for reducing the life cycle of a die has emerged as soldering between aluminum alloys and the die mold materials, resulting in the phenomenon that the surface defect of the die mold originated from soldering provides serious defects for casting products[1−5]. In order to avoid the soldering between aluminum alloys and the die mold, surface protection efforts of the die via plasma vapor deposition(PVD) and/or chemical vapor deposition (CVD) have been attempted[6−8]. However, when the structure of the product (i.e., the structure of die) is complex, the compatible and effective coatings are limited. At the same time, the PVD process often requires strictly controlled coating condition of a sputtering machine and special efforts are sometimes needed for the coatings of complex products. The CVD process also often requires a specific remedy for coating conditions[6−8].

It has been specially noted that the pack cementation process receives a credit for cost-effective and high bond strength between a coating layer and a substrate due to diffusion processes and the possibility of mass production[9−10]. Besides several excellent properties for diffusion pack coatings, a special attention has not been given to the surface protection effects of SKD61 alloys subjected to the pack cementation process. At the same time, the widely used SKD61 mold undergoes a circumstance of repetitive thermal fatigue during die-casting. The direct observations and analyses of the interface have not been clearly identified. In the present study, in order to examine the surface protection effect of the pack-coated SKD61 alloy, soldering effects of aluminum alloys on the pack-coated SKD61 alloys were investigated under simulated die-casting conditions.

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2 Experimental

Rectangular pieces with a size of 20 mm (length)×20 mm (width)×2 mm (height) for pack cementation coatings were prepared made of SKD61. The chemical compositions of SKD61 and ALDC12 alloys are shown in Table 1.

Table 1 Composition of as-received SKD61 and as-received aluminum alloy (ALDC12) determined by spark emission spectrometer (mass fraction, %)

Alloy	Al	Si	Fe	Cr	Cu	Mo
SKD61	0.02	0.85	Bal.	5.24	0.11	1.08
ALDC12	Bal.	10.90	0.9	−	1.87	−

Before the pack coatings, the surfaces of the SKD61 and ALDC12 alloys were treated by a micro sand blaster with a powder size of 20 μm followed by ultrasonic cleaner.

For the Si pack cementation process, Si powder (40%), NaF powder (10%) and Al_2O_3 (50%) were mixed by a slow milling machine for 3 h. After a completed mixing was confirmed, the mixed powders were inserted in a mold with SKD61 pieces, and the mold was completely sealed by bolts and nuts. The mold containing SKD61 alloys and powder mixture was isothermally heat treated at 900 ℃ for 10 h under an Ar gas atmosphere. The schematic diagram of the pack cementation process is shown in Fig.1. The microstructures of the cross sections of the as-coated SKD61 alloys were investigated by SEM (Secondary electron microscopy) with EDS (Energy dispersive spectrum) analysis. Also, XRD (X-ray diffraction) was carried out for phase identification.

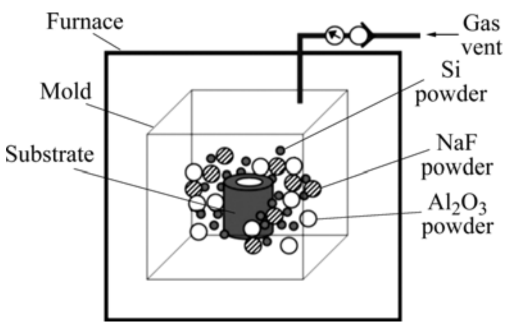

Fig.1 Schematic diagram of pack cementation process

In order to identify the interface reactions and surface protecting effects of SKD61 alloys on liquid aluminum alloys (ALDC12), the pack-coated SKD61 alloys were dipped into a liquid ALDC12 held at 680 ℃. Following 2 h of dipping, the specimen was pulled out and air-cooled. The interface morphology was investigated via SEM and EDS.

3 Results and discussion

Fig.2 shows the morphologies of the coated surface and cross sections of as-pack-coated SKD61 alloy. It is noted that a surface coating layer with thickness of about 20 μm is observed as a result of isothermal annealing at 900 ℃ for 10 h. A few pores are observed in the coating layer. The pores in the coating layer are originated from micro sand blasting treatments of the SKD61 alloys before subjecting to the coatings. The results of EDS analysis is listed in Table 2.

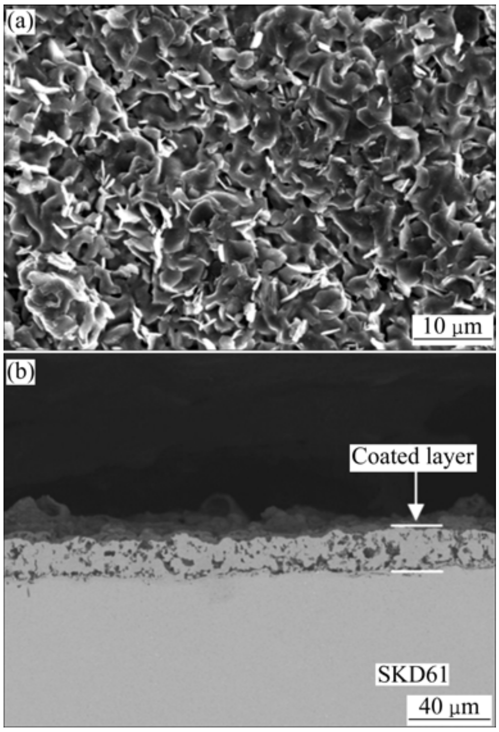

Fig.2 SEM back scattered images of as-coated surface (a) and cross-section (b) of as-pack-coated SKD61 alloy

Table 2 Composition of as-coated layer (molar fraction, %)

Position	Si	Fe	Cr	Al
Outer surface	32.61	37.96	1.41	10.33
Coating layer	36.43	45.58	4.40	−
Substrate	2.73	91.35	5.11	0.17

It is clear that the content of Si increases as a result of the Si pack coating. It seems that the Al content obtained from the surface is due to the anti-sintering materials (Al_2O_3). From XRD analysis, the coating layer is identified as ε-FeSi, as shown in Fig.3.

Figs.4 and 5 show the results of the dipping experiments of the SKD61 alloy (uncoated) in the liquid Al alloy (ALDC12). For the uncoated SKD61 alloy, there

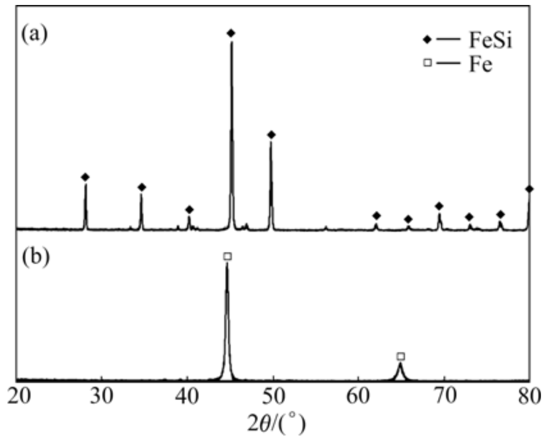

Fig.3 XRD patterns: (a) As-coated SKD61, indicting FeSi phase produced during isothermal annealing at 900 ℃ for 10 h; (b) As-received SKD61 substrate

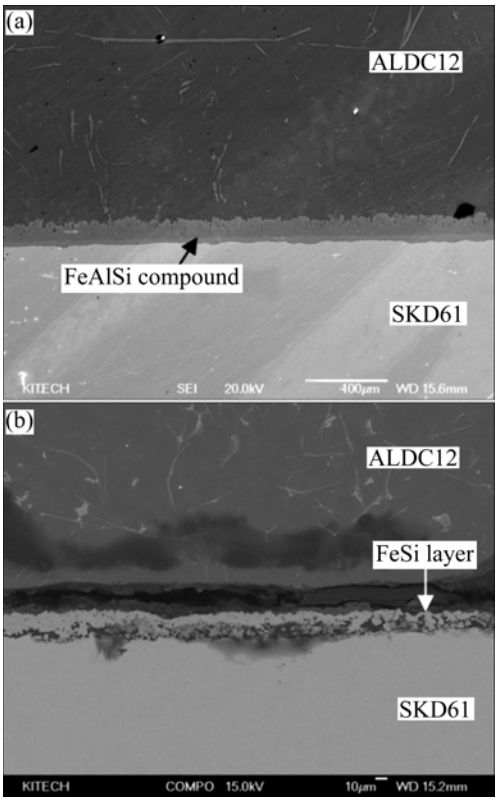

Fig.4 SEM back scattered images of SKD61 alloys uncoated (a) and Si-pack coated SKD61 alloy dipped in liquid ALDC12 alloy at 680 ℃ for 2 h (b)

are compounds between the uncoated SKD61 alloy and the liquid ALDC12 alloy (Fig.4(a)). The compounds are identified as Fe-Al-Si alloys with a composition of 14.59Fe-52.86Al-32.55Si (molar fraction, %) as a result of EDS analysis. When SKD61 molds are dipped in a liquid aluminum silicon alloys, FeAlSi compounds are produced from the interdiffusion of Al and Si in the liquid aluminum alloys and Fe substrate[11−12].

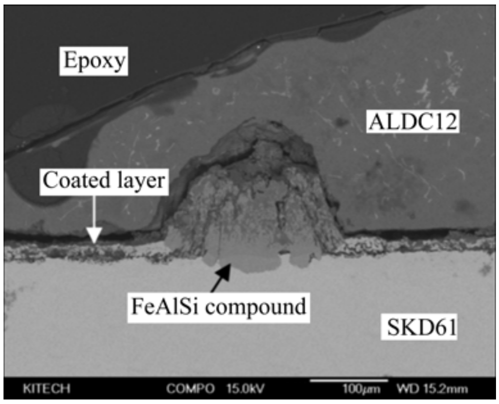

Fig.5 SEM back scattered electron image of poorly conditioned area, showing defect of coating layer inducing interdiffusion reaction and producing FeAlSi compounds

However, for the pack coated SKD61 alloys, Fe-Si alloys are synthesized from pack cementation coatings, and there is no compound formed when the SKD61 alloys are dipped in the liquid aluminum alloys (the same dipping condition for the uncoated SKD61 alloy) as shown in Fig.4(b). It is manifested that the coating layer serves as a diffusion barrier between the liquid ALDC12 alloy and the SKD61 alloy, leading to the phenomenon that nucleation and growth of the FeAlSi compounds are prohibited in the selected kinetic time frame. However, it is also observed that if the coating layer is not sound enough to protect the SKD61 surface when crack or separation of the coating layer and the interfusion reaction occur (Fig.5). Further investigation on the surface protection effects in various liquid alloys and time frames is being underway. The current observation and analysis clearly show that the surface protection effect via Si pack cementation is effective and promising, even though the coating process is relatively simple and cost-effective.

4 Conclusions

1) The surface protection effects of Si pack coated SKD61 alloys on liquid aluminum alloys (ALDC12 alloy) were investigated under simulated die casting conditions.

2) When a powder mixture of silicon (coating material), NaF (activator) and Al_2O_3 (anti-sintering material) together with SKD61 alloys pieces are heat treated at 900 ℃ for 15 h, a uniform layer of the ε-FeSi phase is produced on the SKD61 alloy pieces.

3) When the coated and uncoated SKD61 alloys are dipped in the liquid ALDC12 alloy, the interdiffusion layer that might induce defects for SKD61 alloys is not produced for the Si-pack coated SKD61 alloys. However,

for the uncoated SKD61 alloy, FeAlSi compounds are produced.

4) It is clear that the coated FeSi phase serves as a diffusion barrier for the formation of diffusion layer, and the pack coating process is promising for protection of SKD61 alloys during die-casting process.

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